Plant Diversity and Hydrological relations to groundwater in the Riparian Zone of Cerrado in Mato Grosso (Brazil)

Dissertation

zur Erlangung des mathematisch-naturwissenchaftlichen Doktorgrades

“Doctor rerum naturalium“

der Georg-August-Universitat Göttingen

im Promotionsprogramm Geowissenschaften/ Geographie

der Georg-August University School of Science (GAUSS)

Vorgelegt von

Taciana Ziembowicz

Aus São Luiz Gonzaga, Rio Grande do Sul, Brasilien

Göttingen, 2018

Betreuunhgsausschuss:

Prof. Dr. Gerhard Gerold (Doktorvater), Fachgebiet Landschaftsökologie, Georg-August Universität Göttingen

Prof. Dr. Hermann Jungkunst, Abteilung Geoökologie und Physische Geographie, Universität Landau/ Koblenz.

Mitglieder der Pruegungskommission:

Referent: Prof. Dr. Gerhard Gerold (Doktorvater), Fachgebiet Landschaftsökologie, Georg-August Universität Göttingen

Korreferent: Prof. Dr. Hermann Jungkunst, Abteilung Geoökologie und Physische Geographie, Universität Landau/ Koblenz.

Weitere Mitglieder der Pruefungskomission:

Prof. Dr. Daniela Sauer, Abteilung Physische Geographie, Georg-August Universität Göttingen

Dr. Stefan Erasmi, Abteilung Kartographie, GIS & Fernerkundung, Georg-August Universität Goettingen

Dr. Steffen Möller, Abteilung Physische Geographie, Georg-August Universität Göttingen

Dr. Michael Klinge, Abteilung Physische Geographie, Georg-August Universität Göttingen

Tag der müdlichen Prüfung: 05.04.2018

“It is not the strongest of the species that survives,

not the most intelligent that survives.

It is the one that is the most adaptable to change.”

Charles Darwin

Table of Contents

List of Tables

List of figures

Summary

The riparian zones are essential to environmental quality, providing human society with several ecosystems services. Nonetheless, in tropical ecosystems, an intensive overexploitation of resources can hinder their resilience thresholds, compromising key ecological mechanisms that are arguably not yet fully understood. In the Brazilian Cerrado savannah, which is connected to many river basins with abundant groundwater, knowledge gaps on the relationships between hydrological parameters and plant diversity still exist. In intensively cultivated agricultural areas with remaining riparian vegetation (RV), the ways in which vegetation distribution and plant diversity are related to groundwater dynamics (seasonal groundwater level change) as well as the nutrient content of different water fluxes and how RV maintain water quality are topics that remain unclear. Previous studies have been conducted on the diversity and distribution of Cerrado gallery forest plants, but specific research related to vegetation and groundwater nutrients and dynamics is scarce. To bridge this gap, this thesis, under the umbrella of the CarBioCial project (Gerold, 2017), investigated the ecohydrological relationships between vegetation, groundwater dynamics and nutrients in a riparian zone of the Cerrado in the Campo Verde municipality. Groundwater depth, as well as variations in nutrient content were measured over a two-year period (2014-2016), comprised of both wet and dry seasons, together with a phytosociological and floristic survey. Relationships between the measured variables of interest were then statistically evaluated by clustering and fitting environmental variables with a detrended correspondence analysis.

Diversity, floristic and structural patterns of riparian zones in the Cerrado at four different transects were analysed first (Chapter 4.1 and 5.1). Three different types of vegetation inside the riparian areas were compared, namely the *campo de murundus, cerrado sensu strictu,* and gallery forest, giving a total of 38 plots of 20 x 30 meters. The data analysis was based on α-diversity indexes and structural patterns obtained from phytosociological measures (abundance, frequency, and dominance). In the *campo de murundus,* a total of 706 individuals were registered, distributed among 32 families, 46 genera and 64 species. At the *Cerrado sensu strictu,* 1937 individuals were sampled, distributed among 35 families, 62 genera and 99 species. In the gallery forest, a total of 370 individuals were sampled and distributed among 34 families, 62 genera and 82 species. The α-diversity values in *campo de murundus* and in the *cerrado sensu strictu* were within the expected range, despite that the patches that were surrounded by cropland and/or pasture. In gallery forests, the diversity of plants suffers from human activities such as livestock grazing and selective logging. Our

results show that riparian zones do not maintain their plant diversity in Cerrado regions, due to such human activities. Within our study area, the riparian zone was colonized by plant species usually found in Cerrado, Atlantic rainforest, Amazon rainforest, and Caatinga ecosystems. This plant-based colonization developed a heterogenic environment adapted to the conditions of the landscape. The waterlogged conditions within the *campo de murundus* vegetation type, located between earth mounds, formed a habitat for plant species that can survive in saturated and flooded conditions. The earth mounds (islands) themselves provide a drier environment for the typical Cerrado species to flourish.

Secondly, we assessed whether or not the water quality is maintained in the riparian zone (Chapter 4.2 and Chapter 5.2). We compared water nutrients from base flow and stormflow levels of the river discharge, overflow and groundwater from the inner (gallery forest and *campo de murundus*) and surrounding sites (cropland area = PLU) of the riparian zone. The water quality was analysed separately according to hydrological pathways and grouped by events and compared pair-wise using the non-parametric Mann-Whitney test. We found that the riparian zone contributes to the maintenance of water quality, as the concentration of several nutrients (e.g., DIC, SO_4^{2-}, S, K, P, Mg) was reduced along the hydrological pathways from cropland to the river, passing through the RZ. The vegetation in the riparian zone of Transect 1 was formed by several pioneer plants that regenerated degraded areas in the Cerrado region.

Thirdly, we analysed possible relationships between plant diversity, groundwater table depth and change, and nutrient concentrations (Chapter 4.3 and 5.3). For this, 18 wells were placed in 18 plots within Transects 1 and 2, which consisted of vegetation from the gallery forest and *campo de murundus* vegetation zones. The main findings highlighted relationships between the groundwater table depth, TIC and the *campo de murundus* vegetation zone, as well as copper and zinc with the gallery forest vegetation zone. The results for the gallery forest indicated no groundwater level variables, which was correlated with this vegetation type. This underlines a strong difference between the two vegetation types. Groundwater variation is shown to be a dominant factor in the *campo de murundus* zone and its plant diversity. In addition, the presence of one plant species in particular, *Tachigali vulgaris,* indicates a specific hydrological regime, i.e. that the groundwater level reaches the soil surface layer, maintaining waterlogged conditions for several months. In addition, the *Miconia albicans species* was strongly correlated with total inorganic carbon. Also, *Tibouchina stenocarpa*, *Maprounea guianensis, Xylopia aromatica*, and *Vismia guianensis*

were strongly correlated with *campo de murundus*. Two other plant species (*Cordia bicolor* and *Sacoglottis guianensis*) were correlated with the gallery forest vegetation type. We concluded that studies which can establish functional approaches between these variables are necessary to better understand the extent to which the groundwater can shape the plant diversity in the riparian zones of the Cerrado.

Dedicated to Gabriel, Dante
and Otto

Acknowledgements

Throughout this journey I have had very difficult and very happy moments. However, along the way several people were essential in helping and guiding me. First of all, I want to thank my parents, Solange and Joaquim, who gave me the strength and courage to pursue an academic career. In addition, my husband Gabriel who held my hand and gave me the mental and scientific advice I needed. I also want to thank my son, Dante, who took my mind away from the scientific environment, and the little baby in my belly, growing and helping me to find the focus in the final moments of this PhD. I want to thank my two brothers, Giuliano and Fernando and their wives, Joelma and Alessandra for being part of my life, my family.

I am grateful for the support of my supervisor Prof. Dr. Gerold who was always open to talk about science and improve our work. My colleagues and friends at the department are very special to me, Rodolfo, Flavia, Thorsten, Wiebke, Petra, and Anja, as well as the Brazilian students, Tulio, Jonas, and Gilmar.

I am grateful for the financial support from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES, Brazil for the doctoral grant. Finally, I am thankful for Germany, this amazing country that has become my second home.

1. Introduction

1.1 Background

The neotropical Brazilian savanna is commonly called the Cerrado. Occupying 23% of the country, it covers Brazil’s central plateaus and is its second largest biome. The Cerrado provides Brazil with 43% of its surface water (Furley, 1999; Klink & Machado, 2005, Furley, 2007, Myers, Mittermeier, Mittermeier, Fonseca, & Kent, 2000, Strassburg et al., 2017)**.** The Cerrado ecosystem presents different vegetation types, with woodlands, savannas and open grassland. The Cerrado is therefore considered a woody savanna, due to its changes from woodlands or forest with mostly arboreal species, and forming a dossel layer, to a savanna where arboreal and shrub species spread over a grass layer without building a dossel. It additionally can also comprise grasslands that contain mainly herbaceous and some shrubs individuals (Furley, 1999, Furley, 2007, Ribeiro & Walter, 2008). The Cerrado is thus subdivided into three main formations: forests (woodland), savannas and fields (grassland) (Fig. 1). The woodlands can be split into ciliary forests, gallery forests, dry forests and savanna forests (also called *Cerradão*); the savannas are divided into Cerrado denso (dense), Cerrado *sensu stricto*, Cerrado ralo (sparse), Cerrado rupestre (rocky), veredas (wetlands), parque cerrado or *campo de murundus* (floodplains) and palmeiral (palm grooves); the grasslands include campo sujo (dirty field), campo limpo (grassland) and campo rupestre (rocky fields) (Ribeiro and Walter, 2008).

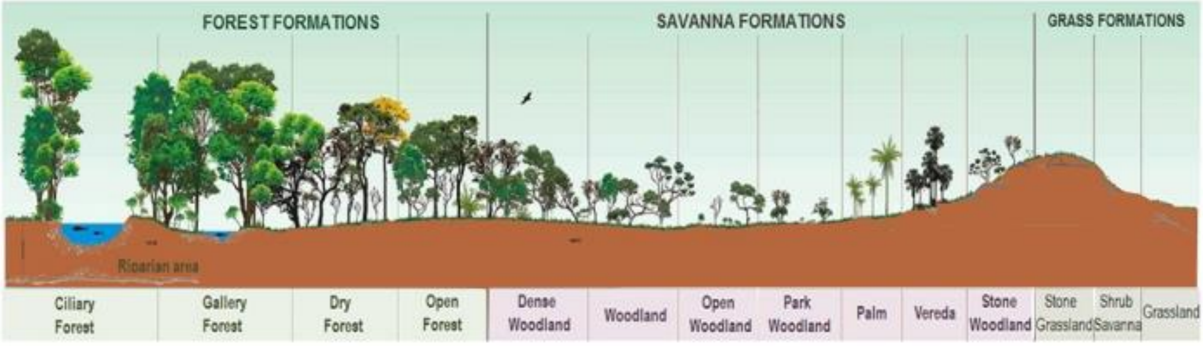

Figure 1. Cerrado biome phytophysiognomies. The graphic depicts the three main vegetation formations and their subdivisions. Adapted from Pereira et al. (2014).

The Brazilian Cerrado is a world biodiversity hotspot, with high levels of endemism as well as species richness, and is considered to be the most diverse savanna in the world (Furley, 1999; Klink & Machado, 2005; Myers, Mittermeier, Mittermeier, Fonseca, & Kent, 2000). The Cerrado's flora contains between 3000 to 7000 angiosperms species, several being endemic (Castro et al., 1999). However, only 7.5% of this environment is being protected by public conservation areas. Of the private property located within this biome, only 20% of the territory must be maintained for conservation according to the Brazilian environmental legislation. As a result of the most recent changes in Brazil's Forest Code, 40% of the remaining Cerrado vegetation can nowadays be legally altered. More than half of the Cerrado has already been transformed into agricultural lands, manly producing corn, soya, cotton, or serving as pastureland for cattle (Klink & Machado, 2005; Ratter, Ribeiro, & Bridgewater, 1997).

The vegetation formations that occur along rivers are called riparian forests or riparian zones (RZ); there is high plant diversity in these zones, with 33% of the plant diversity of the whole biome, rendering them only second to the Cerrado *sensu stricto* formation that embraces 35% of the floristic biodiversity (Klink & Machado, 2005a; Felfili et al., 2001). Several plant species which are native to two other Brazilian biomes, the Amazon and the Atlantic rainforest, also found throughout the Cerrado, especially in the gallery forests, where the wet conditions necessary for plant growth in rainforest biomes are also present (Oliveira-Filho and Ratter, 1995). This special feature of the Cerrado environment is due to the position that it occupies between two types of rain forests (Oliveira-Filho & Fontes, 2000). Several gallery forest species are habitat generalists, occurring in the Cerrado as well as in other biomes of Brazil (Brazilian Flora, 2017).

If a riparian zone is vegetated, it can provide several ecosystem services, such as soil water storage, soil erosion control, and carbon storage, creating connectivity in the fragmented landscape, and conserving water quality (De Steven and Lowrance, 2011; Fremier et al., 2015; Garrastazú et al., 2015). The majority of the Cerrado's riparian zones exist among intensive agricultural land, mostly surrounded by large crop areas, where a great amount of agrochemicals are employed (Felfili, 1995). Notably, these areas usually show changes in the stream hydrochemistry due to agricultural activities, with an increase in the nutrient content in streams mainly in the wet season (Bustamante & Markewitz, 2010). Additionally, the alteration of undisturbed Cerrado areas results in runoff intensification and reduction of groundwater recharge, because normally the infiltration rates are higher in natural vegetation areas when compared with areas covered by pasture and cropland (Oliveira, Nearing, & Wendland, 2015).

Woody riparian zones have a higher capacity to retain pesticides coming from croplands than do RZs with grasses and shrubs. On a farm in the USA with three different RZs, Lowrance and Sheridan (2005) verified the capacity of woody riparian zones to reduce nutrient content, such as nitrate, ammonium and total potassium, coming from upland cropland. Moreover, Osborne and Kovacic (1995) revealed that vegetated riparian zones from an agricultural area in the USA substantially reduced the nitrates in shallow groundwater. One exception was found in a Cerrado catchment area near Ponta Grossa, Brazil, where neither the types of vegetation nor different widths of RZ were found to affect the concentration of atrazine (Aguiar Jr. et al., 2015).

Riparian zones were also found to play a role in maintaining water quality in the Cerrado. Parron and Markewitz (2010) found that RZs from an ecological reserve were efficiently absorbing nitrogen and potassium from the stream water. Similarly, Markewitz et al. (2006) observed in another protected area that the RZs control the nutrient content from the stream water, since it had low levels of elements such as calcium, magnesium. Again, there is evidence that a vegetated RZ helps to maintain the water quality in landscapes degraded by agroindustry activities and urban settlements (Naiman and Decamps, 1997). The nutrient uptake of plants in wooded riparian zones is argued to be the main reason for the maintenance of water quality (Gyawali et al., 2013), since woody plants are better uptakers than grassy plants (Naiman and Decamps, 1997).

The Cerrado’s riparian areas present a particular ecological aspect. They contain tropical forests and savanna vegetation, with a sharp transition between them (Ribeiro & Walter, 2001). The constitution of this unique savanna-forest boundary is related to edaphic factors, natural fire, herbivory and water regime. Normally, savanna soils have a very low nutrient content that affects the structure, diversity and distribution of vegetation (Bond, 2010; Rodrigues et al., 2016). The poor availability of nutrients in the soils affect tree height (Rodrigues et al., 2016), basal area, and species richness (Neri et al., 2012), although other reports debate this (Ruggiero et al., 2002a). Most of the Cerrado formations develop on intensively weathered, porous and well-drained soils, characterized by the presence of sandy particles (Lopes and Cox, 1977). The soil’s water regime also performs an important role in the development of the vegetation in the Cerrado; while soil water is limited on plateau and upper slopes of interfluves, gallery forests in the valley bottoms have a wetter soil water regime, due to flooding and shallow ground water levels (A. T. De Oliveira-Filho et al., 1989).

In the Cerrado, fire is a natural occurrence and has an ecological function, controlling the development of plant species, and negatively impacting tree height and tree populations (Staver and Bond, 2014). Particularly, the savanna-forest boundary develops as a dynamic process of plants species advancing and retreating after a fire event (Hopkins, 1992). Natural fires inhibit some vegetation by damaging or killing bark tissues, and even seeds, and roots by heating the surface soil layers (Uhl et al., 1981). In reaction to fire, plant species with thicker bark (trees) and fire-tolerant plants are common in the Cerrado (Hoffmann et al., 2009a). In addition, herbivorous fauna play an important role in forest-savanna boundaries, feeding on and reducing the development of some plants (Longman & Jeník, 1992). Herbivory includes grazing and browsing, with the former intensifying tree growth rates and the latter causing a reduction in tree growth (Staver and Bond, 2014).

Rainfall seasonality and total rainfall influence plant life dynamics and can lead to either a moisture deficit or waterlogging of the Cerrado ecosystem, depending on the type of the soil (Goldstein et al., 2008). In general, wet soils are necessary for forest development, whereas dry soils are more common in savannas formations, delimiting which plant species will develop in which zones (Goldstein et al., 2008). The mixture of woody and herbaceous plants in the Cerrado ecosystem (from deep-rooted to shallow-rooted plants) make use of soil water resources from different depths. Very deep-rooted trees function as hydraulic lifts, influencing the water balance of the plant in itself and also the neighboring plants and shaping the Cerrado environment. This process (Caldwell et al., 1998) in a *Cerradão* formation is connected to the presence of more trees that help keep the soil wetter than in, for example, a *Campo sujo* formation (Scholz et al., 2002).

Within the Cerrado exist springs and headwaters for three important aquifers in Brazil – the Guarani, the Bambuí and the Urucuia (Gaspar & Campos, 2007; Iglesias & Uhlein, 2008; Ribeiro, 2008). This biome also supplies six major river basins – the São Francisco, the Amazon, the North-Northeast Atlantic, the East Atlantic, the Tocantins, and the Paraná-Paraguay, thus providing Brazil with 43% of its surface water (Oliveira et al., 2014; Strassburg et al., 2017). The Cerrado ecosystem has adapted and established itself under specific environmental conditions (fire, poor soil nutrient content, drought), where the precipitation has a strong influence, recharging the water in the soil and maintaining the groundwater reservoir (Campos, 2004; Lousada et al., 2005). The vegetation helps to maintain these typical climatic conditions, though high deforestation acts to reduce precipitation and increase temperatures (Lean and Rowntree, 1999; Polcher, 1995; Zhang et al., 1996). In the

Cerrado the water regime is characterized by two different seasons: the wet season extends from October to April and a dry season from May until September, with 90% of mean annual precipitation occurring during the wet period (Klink and Machado, 2005).

The quantity and quality of accessible water is considered of high relevance in explaining functional plant diversity in many ecosystems around the world (Greaver and Sternberg, 2007; Romero-Saltos et al., 2005). Differences in elevation over short distances and related fluctuations in soil water resources can affect plant traits related to water balance and plant water use (Villalobos-Vega et al., 2014a). Studies have shown that differences in woody density and vegetation diversity are related to groundwater fluctuations and different positions along topographic gradients (Rhymes et al., 2014; Zhou and Li, 2010). In the Cerrado ecosystem, evidence was found for a richer diversity of woody species on higher slopes with deeper groundwater, whereas grasses are richer on lowers slopes with shallow groundwater (Rossatto et al., 2012; Villalobos-Vega et al., 2014a). Furthermore, the variation in vegetation types along Cerrado topographical gradients change when the groundwater reaches the soil surface layers, longer waterlogging periods leading to less plant richness and diversity (Eiten, 1972; Ferreira-Júnior et al., 2016).

In the Cerrado, the natural process of groundwater reaching the soil surface and staying there for longer periods results in waterlogging conditions that give rise to a specific environment, the *campo de murundus*, which is adapted to it (De Oliveira-Filho, 1992a; Marimon et al., 2015, 2012). With the hydrological conditions of the *campo de murundus*, the plains areas are colonized with herbaceous species, interspersed with earth mounds where arboreal and arbustive plants develop (Marimon et al., 2012). The earth mounds help to maintain the root systems away from (above) the saturated soil (De Oliveira-Filho, 1992a), since Cerrado plants are intolerant to anaerobic conditions (Jirka et al., 2007; Oliveira et al., 2016a).

Some attention has been paid to a possible impact of fluctuations in groundwater levels on vegetation structure along topographical gradients (Goldstein et al., 2008; Lowry et al., 2011; Schenk and Jackson, 2005, 2002; Villalobos-Vega et al., 2014a). Koirala et al. (2017) state that the interactions between groundwater and vegetation are not well understood worldwide, since factors affecting these such as extent, timing and conditions are not clear. It is known that groundwater provides the vegetation with moisture necessary for evapotranspiration (Koirala et al., 2017). Likewise, Fan, Li, & Miguez-Macho (2013) consider that groundwater has a role in driving ecological patterns on a global scale, notably with regard to wetlands, peatlands, riparian wetlands in the Amazon, Pantanal, and Chacos regions, since shallow groundwater is a limiting factor for several plant species, or essential to others that need water stored in the soil. Particularly, Lowry, Loheide, Moore, & Lundquist (2011) maintain that the distribution and composition of plant species in riparian zones, wetlands and floodplains are intensely influenced by groundwater. In addition, Oliveira et al. (2016) found that groundwater depth influences the distribution of Cerrado plants, since the recharge of groundwater decreases with the increase of Cerrado vegetation density (grassland to woodland).

A further variable that can impact plant diversity is nutrient availability, which defines a specific geobotanical aspect of the Cerrado. Scientific evidence correlating the soil nutrient content and vegetation diversity is ambiguous with regard to the Cerrado. Some previous findings suggest that a deficiency of calcium, magnesium, potassium, sodium, phosphorous and nitrogen are linked with open savanna physiognomies (Furley & Ratter 1988, Haridasan, 2008), and also connected to the Cerrado *sensu stricto* (Ribeiro and Walter, 2008). Some studies of the Cerrado show no significant correlation between soil fertility and diversity, but diversity was connected to high aluminium saturation and exchangeable Al (Ruggiero et al., 2002a). Ratter et al., (2003) found that richer soils showed lower plants diversity in the Cerrado.

The hyperseasonal and seasonal Cerrados are characterised by larger amounts of sand, pH and magnesium, whereas the wet grassland by a higher content of clay, organic matter, aluminium, exchangeable aluminium, phosphorous and potassium (Amorim and Batalha, 2007a). The Cerrado formations were connected to a higher content of exchangeable aluminium in the superficial soil layers, when compared with semideciduous forest, whereas the Campo Cerrado, Cerrado *sensu stricto,* and Cerradão were not differentiated by soil parameters (Cruz Ruggiero et al., 2002a). A recent study showed that a high quantity of manganese in a Cerrado *sensu stricto* formation was positively correlated to tree height (*Virola sebifera*, *Vochysia tucanorum* and *Pterodon emarginatus)* and higher basal area (Reys et al., 2013). Moreover, *Melastomataceae* and *Vochysiaceae* families, typical of the Cerrado, are known to accumulate great amounts of aluminum from the soil in their tissues, this occurring in greater quantity in areas with acid soils and higher availability of this element (Haridasan, 2008). Also plant species of *Fabaceae* family, known as nitrogen-fixing plants, colonize the Cerrado (Soltis et al., 1995).

Despite these interesting findings, the relationship between nutrient content in the water and plant diversity has still not yet been thoroughly investigated. In a riparian zone, plants species composition can be affected by flooding periods and nutrient distribution, and by the amount and solubility of chemical elements (Gregory et al., 1991). Zaharescu et al. (2017) found that riparian vegetation around a lake was influenced by water nutrients, mostly by iron and magnesium from the water of the lake. There have been a few recent investigations attempting to find a possible correlation between groundwater nutrients and plant diversity. Rhymes, Wallace, Fenner, & Jones (2014a) found that groundwater nutrients influence plants species distribution in a dune ecosystem, possibly due to nitrogen impacting species composition. In a single Cerrado study, Villalobos-Vega et al, (2010) could not find any correlation between groundwater nutrients and plants diversity. Nevertheless, the nutrient content of the water and its relationship to plants diversity in the Cerrado RZ has not so far been studied, opening the possibility for new research investigating these ecological parameters. Further scientific investigation is necessary to understand possible ecological interrelationships between groundwater regime, nutrients and plant diversity in the Cerrado's riparian zones.

1.2 Problems Statement

Plant formations and diversity, as well as 44% of endemic species in the Cerrado (Myers et al., 2000) are endangered by ongoing deforestation and agricultural development (Klink and Machado, 2005). Therefore, it is important to maintain the RZs with gallery forests and *campo de murundus*, since a great diversity of plants is located in them (Ribeiro & Walter, 2001). Likewise, maintaining water quality in agricultural areas (Parron et al., 2011) and the carbon storage capacity of these areas (Skorupa et al., 2013) is important. Brazil has reduced gas emissions in the last decade in an effort towards riparian zone conservation according to the Forest Code (Garrastazú et al., 2015). However, the law previously reserving a minimum of 30 meters width of vegetation along the rivers has been changed recently reducing this minimum reduced by half (Garrastazú et al., 2015), which negatively affects the diversity of plants in Brazil's biomes (J. L. N. Carvalho et al., 2009), as well as carbon sequestration (Wantzen et al., 2012), water quality (Markewitz et al., 2006), erosion process (Paulo Tarso S Oliveira et al., 2015) and several other vital ecosystem factors in these areas.

Plant diversity in ecosystems is controlled by a number of local and regional ecological factors, such as soil texture and nutrient content (Conradi et al., 2016), water regime, water fluctuations (Rossatto et al., 2012, 2009; Villalobos-vega, 2010), fire, and herbivory (Staver and Bond, 2014). Specifically with regard to the water variable, groundwater table depth variation (GWTD) (Lowry et al., 2011; Villalobos-vega, 2010) and the chemical element composition of groundwater seem to play a key role (Rhymes et al., 2014; Zaharescu et al., 2017). We need to better understand how these hydro-chemical variables impact vegetation distribution and plant diversity in the Cerrado biome, as they are strongly influenced by the drought and waterlogging that occur in the dry and wet seasons of this ecosystem.

Vegetation diversity in riparian zones provides several ecosystem services, such as maintaining water quality (Aguiar Jr. et al., 2015; Osborne and Kovacic, 1995; Parron et al., 2011; Tabacchi et al., 2000) and erosion and flood control (Hawes and Smith, 2005). A decrease of water quality has already been observed as a result of landscape changes by agroindustry in the Cerrado (Parron et al., 2011; Silva et al., 2010). Because of a worldwide interest in this negative impact on water quality due to areas where vegetated riparian zones are not maintained, a few studies inside well-preserved areas were made in the Cerrado − however these were mostly in ecological reserves rather than in RZ with surroundings highly impacted by agriculture.

The Cerrado riparian zones that are already isolated and fragmented by croplands and farming will have negative pressure in the future, due to the expansion of agroindustry activities. It is estimated that a deforestation of around 31 - 34% of the remaining natural vegetation can occur by 2050 (Strassburg et al., 2017). In addition, deforestation in the RZs will have a negative impact on the regional water household with changes in the water regime of several key Brazilian rivers (Gücker et al., 2009). Likewise, deforestation of the RZs will cause several problems in the local environment, not only affecting water quality, but also erosion control and regional climate (Ratter, Ribeiro, & Bridgewater, 1997).

The ongoing accelerated deforestation process changes the quantity and quality of water resources. It also perturbs the regional atmosphere, affecting cloudiness, humidity and temperature, resulting in changes in runoff processes and in the length of the dry season (Cabral et al., 2015; Rodrigues et al., 2014; Spera et al., 2016). In fact, conversion of the Cerrado vegetation to croplands and livestock pasture is bringing about changes in the hydrological cycle, increasing water runoff and decreasing evapotranspiration or infiltration in the soil, and thus groundwater availability (Spera, Galford & Coe, 2016).

Furthermore, the water quality in Cerrado is depreciated by the agrochemicals used in croplands, which can be found in surface water, shallow groundwater and the bottom sediment of spring waters or rivers (Carbo et al., 2008; Casara et al., 2012; Hunke et al., 2014; Nogueira et al., 2012; Rocha et al., 2015; Rosolen et al., 2015). Previous findings reveal that land cover changes directly affect the hydrochemistry of small tributaries in the Cerrado, with high nutrient content in surface water in croplands and urban areas (Silva et al., 2011). Moreover, the Cerrado’s groundwater is more susceptible to contamination, due to the substrate and soil characteristics, i.e. high infiltration rates and lower retention capacity,; this particularly affects in the southeastern and central-eastern part of Mato Grosso State with its shallow water table depth (Mingoti et al., 2016). Specifically, water infiltration depends on several aspects, such as vegetation cover, substrate and soil parameters (e.g. saturated hydraulic conductivity), as well as relief and geological characteristics – all of which influence the rate of groundwater contamination (Boaventura and De Freitas, 2005; Carrera-Hernández et al., 2012). Further studies with groundwater and surface water monitoring in the Cerrado of Mato Grosso State show contamination by several agrochemicals, such as herbicides (Dores et al., 2008). Still, there are not enough studies on the presence and the persistence of agrochemicals in rivers and groundwater of Cerrado (Dores et al., 2008).

The conversion of natural Cerrado areas to agricultural land will probably result in changes in the local climate and water regime (Hoffmann and Jackson, 2000). Water uptake by plants and evapotranspiration will be reduced due to crop plants and pastures, as will interception of precipitation (Le-Maitre et al., 1999). Changes in land use thus affect groundwater recharge rates and water table depths. A reduction in the water table depth in turn impacts river discharge and can increase the danger of flooding (Le-Maitre et al., 1999). Overland water flow from surrounding cropland enters the RZ. Depending on the extent and type of vegetation cover of the RZ, soil sediments or soluble substances (e.g. agrochemical nutrients) can be retained before reaching the stream water (Dosskey, 2001; Osborne and Kovacic, 1995; Polyakov et al., 2005). During the percolation process, the nutrients are filtered by soil particles and taken up by plant roots, thus reducing their leaching into the groundwater. (Cooper et al., 1987). Thus a possible capacity of the riparian zone plants to remove contaminants with efficiency depends on the extent and type of vegetation established in the area (Aguiar Jr. et al., 2015).

Despite the above-mentioned negative impacts resulting from changes in land use in the Cerrado ecosystem, it is clear that the riparian zones still play an essential role in this biome. In order to better understand the ecological processes going on in RZs, it is important to disentangle some of its key ecological aspects, such as plant diversity and its relationship to hydrological indicators. Knowing how these factors correlate to each other can provide a better understanding of how and whether riparian zones in areas very disturbed by agricultural surroundings are contributing towards maintaining the water quality of the Cerrado ecosystem. Finally, assessing the ecological influences of groundwater variation and its nutrient content on the natural vegetation of the Cerrado can shine further light on the environmental factors that determine plant diversity and plant distribution.

1.3 Aims and hypothesis

In order to fill a gap existing in the reviewed scientific literature, this research has the following aims:

(i) to characterize plant distribution, structure and composition inside the riparian zones of agricultural lands in the Brazilian Cerrado;

(ii) to assess whether the riparian zones are involved in water quality maintenance in the Cerrado ecosystem.

(iii) to assess which plants species can indicate high or low groundwater level regimes,

(iv) to evaluate if groundwater nutrients are linked with vegetation types and plant species;

(v) to determine whether groundwater table depth delineates patterns of plant species diversity.

The following hypothesis sets the frame for the research:

(i) Besides the gallery forest, the *campo de murundus* is also an important vegetation type of the RZ with regard to biodiversity and conservation of Cerrado plants;

(ii) Groundwater levels and their seasonal change is a main environmental factor for spatial plant distribution in RZs;

(iii) Indicator plants for the groundwater regime can be identified;

(iv) Groundwater nutrient concentrations may have an influence on plant diversity;

(v) The plant community in the riparian zone is still contributing to the maintenance of water quality in a catchment area impacted by surrounding intensive croplands.

The plant diversity of riparian zones is reduced by the agricultural development around them, leading to a change in vegetation development to earlier successional stages, smaller plants and reduced plant diversity (Huston, 2005). In order to understand the ecosystem process occurring in the RZs, it is necessary to know which plant species are developing in these areas, as well as their composition and distribution along a gradient of groundwater level, and also their seasonal changes in the RZ. Villalobos-Vega et al. (2014a) verified that tree density and diversity at low elevations in the Cerrado are governed by the intense fluctuations in groundwater table depth and by groundwater reaching the soil surface – i.e. waterlogging − because typical Cerrado plants cannot survive in waterlogged habitats. Moreover, Honghua and Weihong (2010) also confirmed that variation in groundwater table depth can affect the vegetation distribution and species composition in arid regions. Rhymes, Wallace, Fenner, & Jones (2014a) correlated the content of nutrients in the groundwater with the distribution of vegetation in a dune ecosystem and found that nitrogen from that source influences plant species composition. Parron et al. (2011) verified that RZs in the Cerrado are effective in filtering nitrogen and phosphorus. Despite such contributions, it is still an open question whether groundwater nutrients influence vegetation types in the riparian zones of the Cerrado ecosystem. The scientific literature still presents a research gap with regard to the Cerrado riparian zones and their capacity to contribute to water quality maintenance (Lowrance and Sheridan, 2005). A deeper understanding of plant species differentiation and distribution, and their relation to nutrient contents in overflow, groundwater, streamflow and stormflow, is necessary but still lacking (Nóbrega et al., 2017).

2. Study area and site characteristics

2.1 Introduction

The state of Mato Grosso has a population of 3,345,000, occupying a territory of 903,330 square kilometers. Located in the center of the South American continent (IBGE, 2010), it is the third biggest state in Brazil. Moreover, Mato Grosso is partially situated within the so-called Brazilian Legal Amazon, right at the southern edge of the Amazon Basin, and possesses three important Biomes within its borders: the Amazon forest (53% of the state territory), the Cerrado (40%) and the Pantanal (7%) (Fig. 2) (Brando et al., 2013; Richards and VanWey, 2015). At present, agroindustrial activity occupies 37% (335 thousand square kilometers) of the Mato Grosso landscape, and so far 34% of the Amazon forest, 20% of the Cerrado and 5% of Pantanal ecosystems has been converted to crop fields or pastures (Brando et al., 2013b). Between the years of 2000-2012, almost 80,000 km^2 of the tropical forest and cerrado were deforested in the state, due to the demands of agricultural expansion. Nevertheless, in recent years the rate of deforestation has decreased, due to strengthened law enforcement, and to new protected areas and new environmental laws (Richards and VanWey, 2015b).

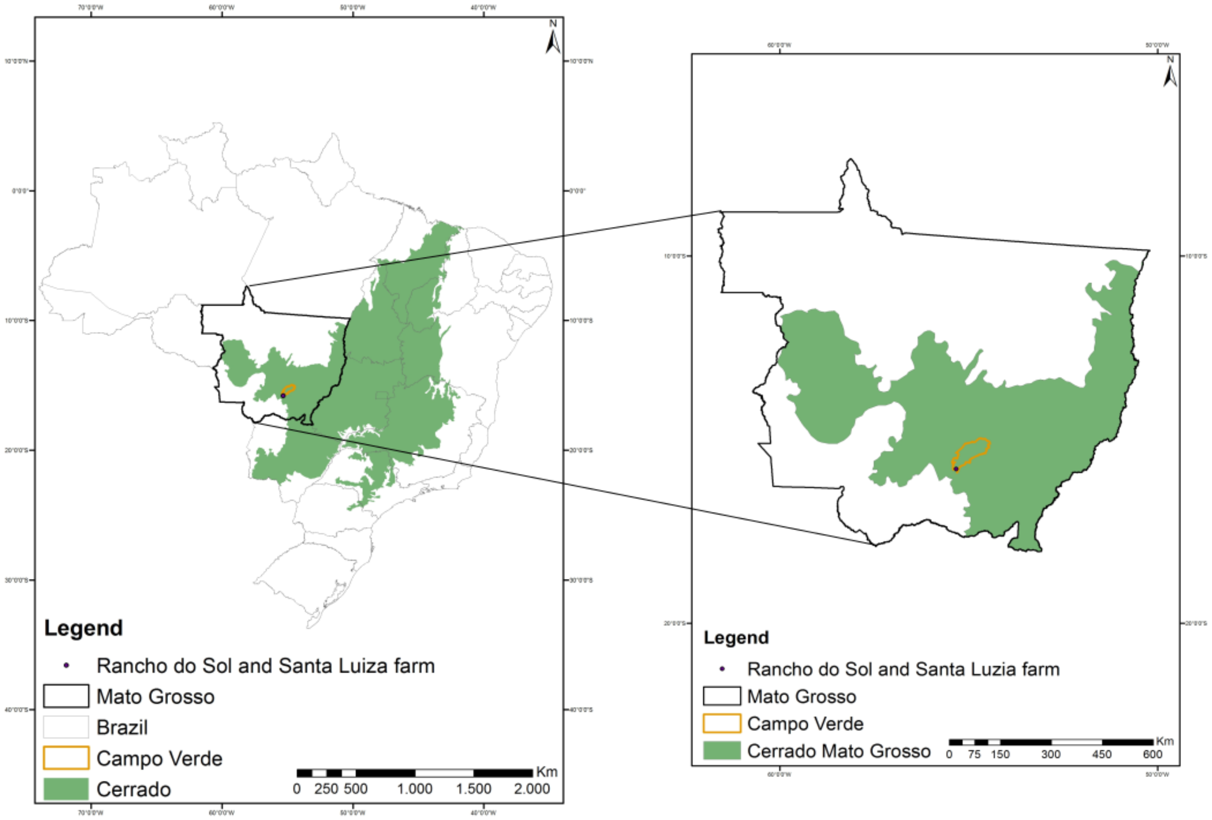

Figure 2. Study area location within the borders of the state of Mato Grosso, showing the Cerrado biome and the Campo Verde community where the two research farms are located.

The state’s economy has developed in the last three decades essentially based on large agro-industrial properties, with governmental political and technological support; this has resulted in intense deforestation. This agricultural expansion was initiated in the 1970’s with the endorsement of the Brazilian government and was driven by large investments in new advanced technologies such as soil management and new crop varieties (Binswanger, 1991). Nowadays, the state is considered one of major producers of agricultural products in Brazil, with soya, corn, cotton, and beef being the most important commodities, exported mainly to Europe, North America, the Middle East and Asia (Richards et al., 2015; Richards and VanWey, 2015b). Additionally, the state is Brazil’s main exploiter of logging, the cutting and processing of timber being responsible for 33% of production in the Brazilian Amazon rainforest (Lentini et al., 2005).

With the aim of clarifying some of the ecological processes occurring in the riparian zones constrained by agroindustry landscapes in the Cerrado ecosystem, our study area was defined as riparian vegetation patches in the Rio das Mortes river basin in the state of Mato Grosso, Brazil. This area extends between latitude 15º 32' 48"S and longitude 55º 10' 08" W and lies within the borders of the community of Campo Verde. Campo Verde has a population of 39,933 inhabitants, occupies 4,768,083 square kilometers and is located 130 kilometers from Cuiabá, the capital of Mato Grosso (IBGE, 2010). The city is situated adjacent to the Chapada dos Guimarães National Park, lying 98.3 kilometers from its border. The community was chosen as a study area of Carbiocial project, because of the headwater catchments of the Rio das Mortes. The Rio das Mortes is the main river in Mato Grosso, being a tributary of the bigger Araguaia River and fully located in the Cerrado ecosystem. The catchment of Rio das Mortes includes small and bigger patches of native vegetation in the Cerrado biome. The studied area is under intensive agricultural use with two main cultivars: maize (*Zea mays*) from February to July, and soybean (*Glycine max*) from October to January (Gerold, 2017; Gerold et al., 2014). Two farms were chosen to be investigated by the Carbiocial project, with the consent of their owners, and included in the present research. The Rancho do Sol farm, located at coordinates 15.797˚ S and 55.332˚ W, has a well-preserved patch of cerrado *sensu stricto* among the crops, acting as a riparian zone. The Santa Luiza farm, located at coordinates 15.743° S, 55.366° W, does not possess a cerrado *sensu stricto* formation, but only few patches of riparian vegetation, mostly gallery forests and *campo de murundus.*

2.2 Climate and Hydrology

Mato Grosso has three main river basins: the Amazon, the Araguaia-Tocantins, and the Paraguai-Paraná, the last two providing Brazil with 55% of its total drainage area (Fig. 3) (Soares et al., 2006). The Rio das Mortes is located within the Araguaia-Tocantins basin. The climate of the Rio das Mortes catchment is characterized as tropical semi-humid, with a pronounced dry season lasting around five months (May-September) during the southern hemisphere summer, and a seven-month wet season, lasting from October to April (IBGE, 2002).

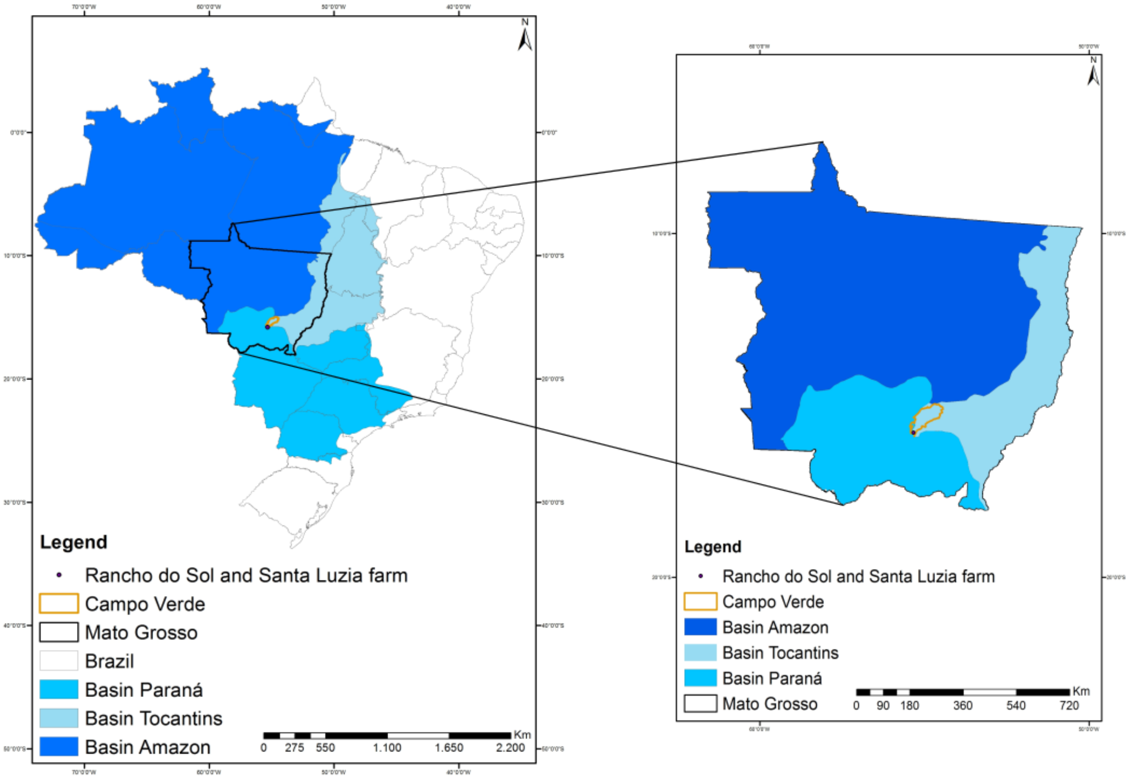

Figure 3. Main rivers basins lying within the Mato Grosso state borders. The Rio das Mortes catchment is located in the Tocantins basin. The two farms where the plots were established are situated close to the intersection of the Tocantins and the Paraná basins.

2.2.1 Temperature and Humidity

The Rio das Mortes basin has annual temperatures ranging between 18 to 35 degrees and is characterized by a tropical semi-humid climate. The Cuiabá city also have temperature between 22.8°C and 27.4°C (Fig. 4). The study area (Campo Verde) was monitored during the years 2014 to 2016 by the Carbiocial project during which temperature values ranging from 20.5°C up to 24.4°C, with an average humidity varying from 59.5% in dry season up to 91.6% in wet season were recorded (Fig. 5) (Gerold, 2017; Gerold et al., 2014).

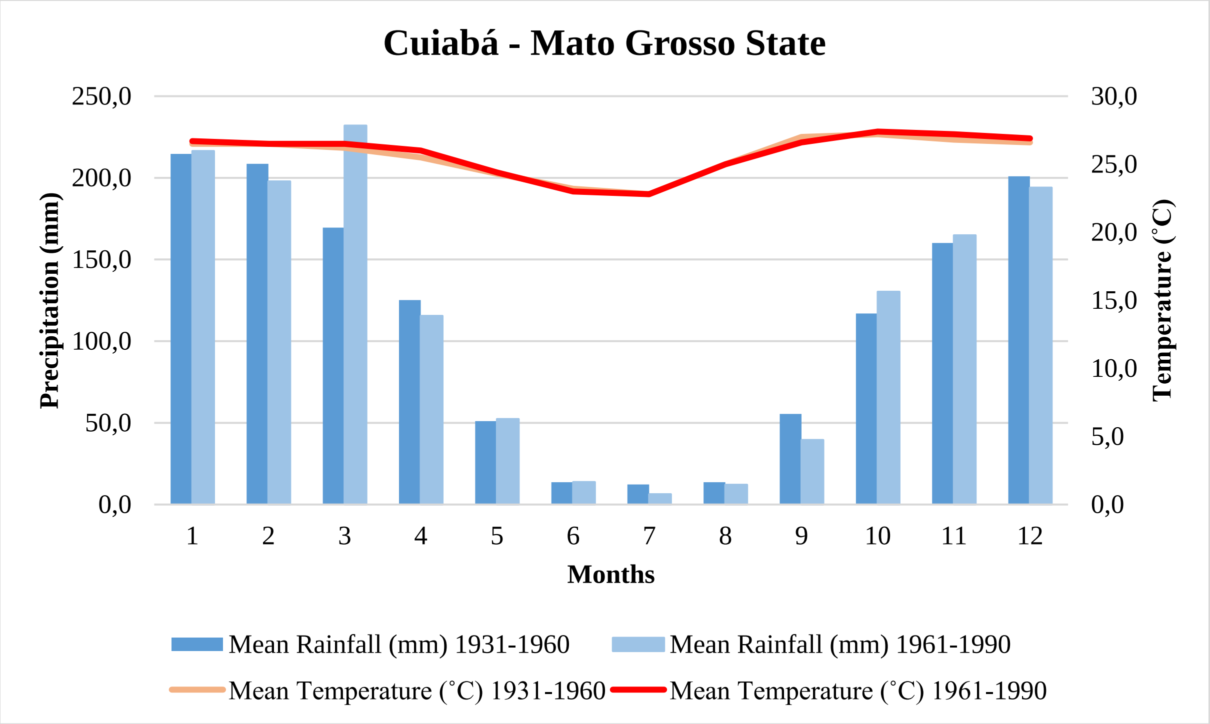

Figure 4. Precipitation and temperature in Cuiabá city between 1931 and 1990.

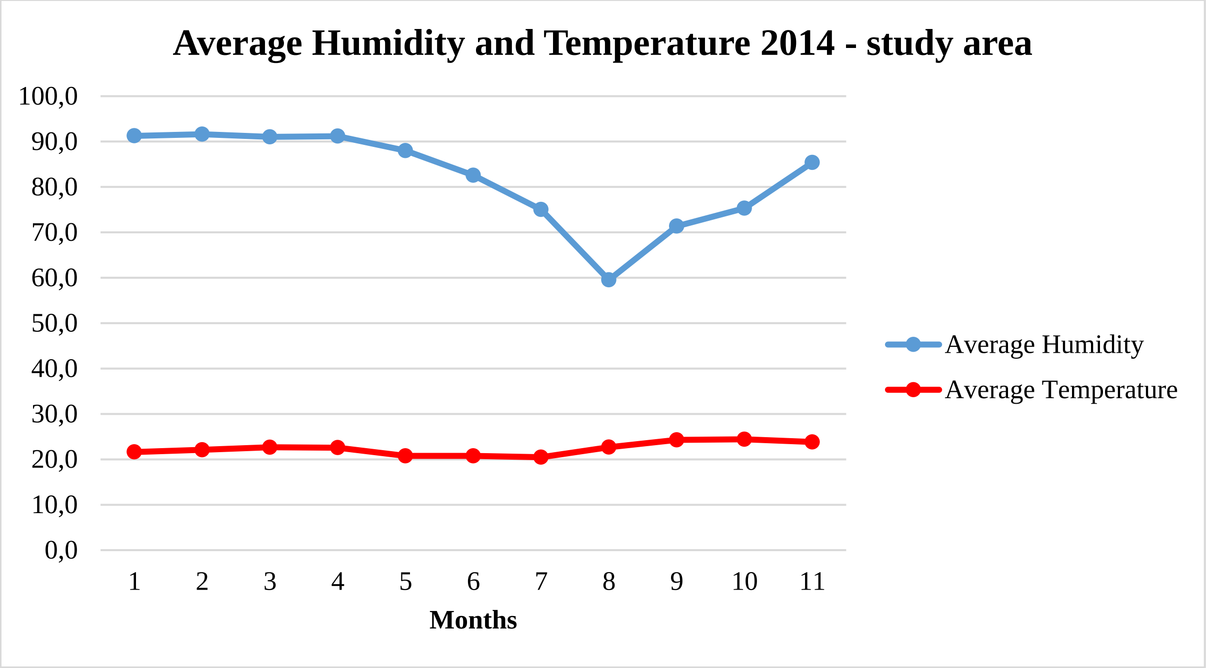

Figure 5. Average humidity and temperature in the study area during 2014. December was not monitored due to technical constraints.

2.2.2 Rainfall

The annual precipitation of the Cerrado Biome is between 600 and 2200 mm, with an average of 1750 mm. The Cerrado receives rainfall from two neighboring biomes with higher levels of rainfall, the humid Amazon forest and the lower levels of the semi-arid Caatinga (IBGE, 2004). In Cuiabá city the precipitation rates are between 6.3 mm during the dry season and 232 mm during the wet season (Fig. 4). Mean rainfall in the area of Campo Verde is 1645.9 mm (Fig. 2.5). The study area (Campo Verde) was monitored in the years 2014 and 2016 (but not in December 2014 or in 2015 due to technical restraints) and had a total rainfall of 1467 mm in 2014 (without December) and in 2016 of 1824.8 (Fig. 6) (Gerold, 2017; Gerold et al., 2014).

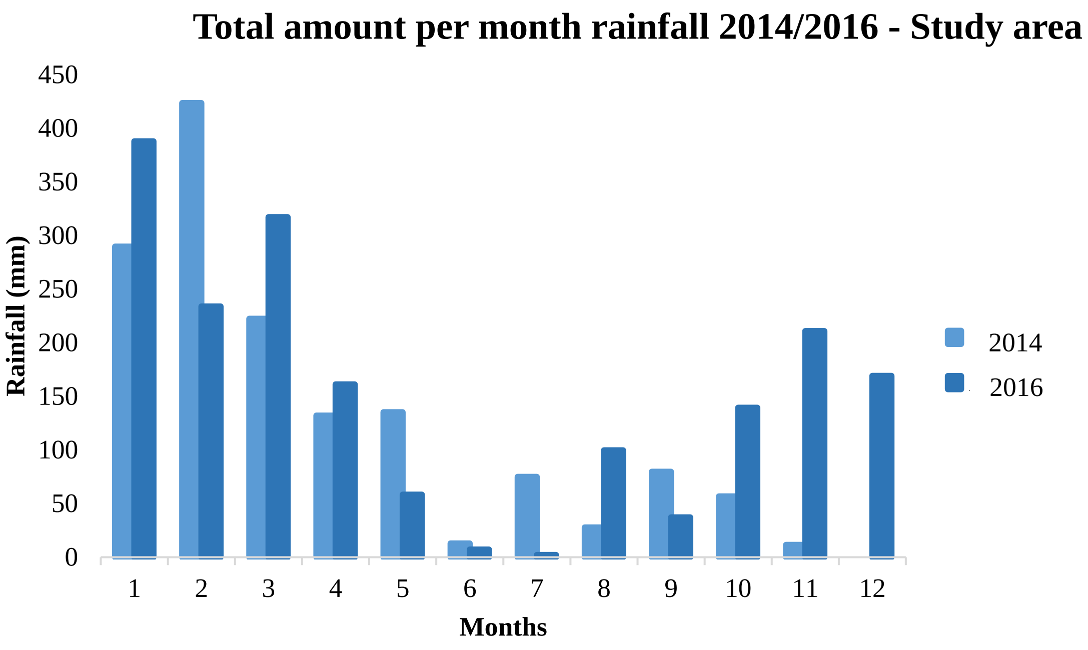

Figure 6. Monthly total amount of rainfall measured in our study area during the years 2014 and 2016. December 2014 and the year of 2015 were not monitored due to technical constraints.

2.2.3 River characteristics

The Rio das Mortes is altogether 1070 km long and covers 17,556 km². It is situated in central Brazil, with its source located at the Serra São Lourenço, Campo Verde (eastern portion of Mato Grosso). Running across the Mato Grosso Plateau, it flows into the Araguaia River, the major affluent of the Tocantins River, one of the largest in Brazil. The whole basin includes 21 municipalities with 277,145 inhabitants, the main economic activities around the river being agriculture and livestock raising (IBGE, 2000).

2.3 Topography and Soil Characteristics

The Cerrado geology is complex, with different substrates and different types of soils. In the Campo Verde region, the predominant soil types are red-latosols and yellow-latosols (Fig. 7) (IBGE, 2002). In the two first transects (Plots 1-18) at the Santa Luzia farm, clay texture was predominant, whereas at the Cerrado *sensu stricto* transects (Plots 19-38) located at the Rancho do Sol farm, sandy texture prevailed (Gerold, 2017; Gerold et al., 2014). In general the soils are dystrophic, deeply weathered, acidic, with sand and clay textures (Amorim and Batalha, 2007; Ratter et al., 1997; Oxisols a. USDA). However, in the classification maps of the Brazilian Institute for Geography and Statistics (IBGE), the soil in the two farms is indicated as sandy, contrasting with the data samples obtained by the Carbiocial project.

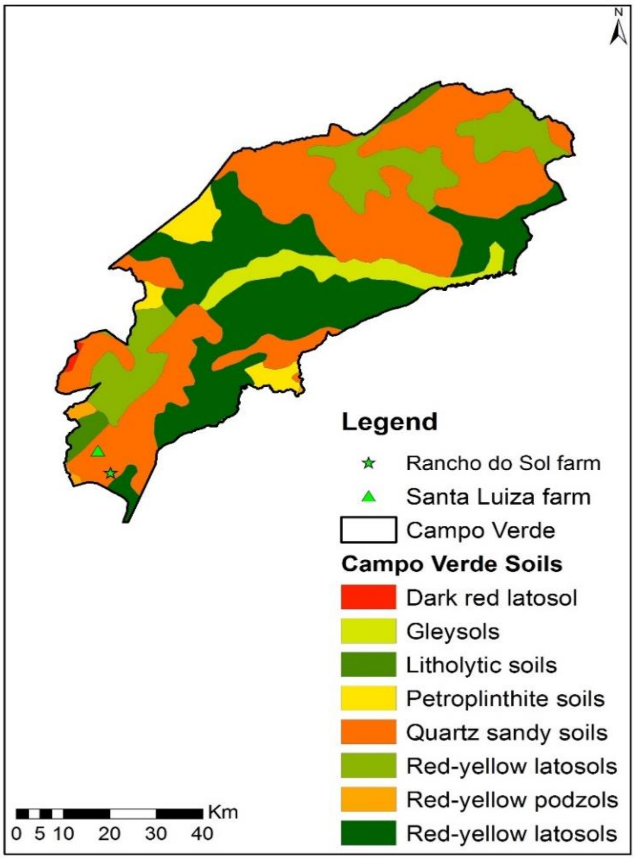

Figure 7. Soils classification at Campo Verde. Note that the soil type for the two research farms are given as quartzitic sandy soils according to IBGE, not the clay texture observed *in locu* at the Santa Luzia farm. Source: IBGE maps, 2002.

2.4 Cerrado biome and riparian vegetation

The Cerrado biome is the second largest in Brazil, with two million km^2. It is located in the Central Plateau of Brazil, being a transition area between the Amazon rainforest and the semi-arid Caatinga biome (IBGE, 2004). In addition to the typical Cerrado formations, the gallery forest is another type of vegetation located along stream courses in this biome. This research project's study area also contains gallery forests (Fig. 8), due to its transects lying in the vicinity of riparian zones.

Figure 8. Gallery forest formation inside Transect 1, Plot 1. Picture taken by the author, 03/2014.

Considering each type of vegetation in the Cerrado, there are specific plant species colonizing each formation that can be commonly found in these areas. Here, we focused on data collection in three specific types of formations that appear along the Rio das Mortes catchment in Campo Verde: the riparian zone woodland (gallery forest), the *campo de murundus* and the Cerrado *sensu stricto*. The riparian zones in the Cerrado present two different types of vegetation adjacent to the river, i.e. the ciliary forest and the gallery forest. The former colonizes only median or bigger rivers, having deciduous trees surrounded by forests that change smoothly to other formations, but do not form galleries. The latter borders only small rivers, with perennial trees surrounded by non-forest formations that sharply change to grassland or savannas. Moreover, gallery forests can also be separated into two subtypes: the flooded and the non-flooded, with typical plants species for each one of them (Ribeiro and Walter, 2008).

In our research area, the riparian zones were flooded gallery forests. This subtype of vegetation formation in the Cerrado usually present the following main species: *Protium* spp., *Miconia* spp., *Tibouchina* spp., *Euterpe edulis, Mauritia flexuosa, Xylopia emarginata, Protium heptaphyllum, Schefflera morototoni, Styrax camporum, Symplocos nitens, Tapirira guianensis, Virola sebifera, Protium heptaphyllum, Tapirira guianensis,* among others (Ribeiro & Walter, 2008).

Besides the gallery forest, two of the delimited transects (1 and 2) present *campo de murundus* formations contiguous to the woodland. Recently, Marimon et al., (2015) defined the *campo de murundus* as characterized by soils with low nutrient levels and high concentrations of organic matter in the earth mounds elevations. On the other hand, the areas of grassland plains between the earth mounds present sandier soils (Marimon et al., 2012). Figure 9 depicts the earth mounds with their typical woody plants species above it. Between the earth mounds, grasses dominate the landscape, with the incidence of the *Tibouchina stenocarpa* species as an additional marker to be observed (Fig. 10 and 11).

Figure 9. A *campo de murundus* earth mound at Transect 2, Plot 16). Note that the earth mounds are colonized by Cerrado species, mostly woody vegetation. Picture taken by the author, 03/2014.

Figure 10. Plains area between earth mounds dominated by grasses and *Tibouchina stenocarpa* at the *campo de murundus* formation, Transect 1, Plot 8. Picture taken by the author, 03/2014.

Figure 11. Plains area between earth mounds dominated by grasses and small shrubs at the *campo de murundus* formation, Transect 1, Plot 3. Picture taken by the author, 03/2014.

The *campo de murundus* can also be recognized by typical plant species, such as *Alibertia edulis, Andira cuyabensis, Eriotheca gracilipes, Maprounea brasiliensis, Qualea grandiflora*, with the *Qualea parviflora* typically located on the earth mounds (Ribeiro & Walter, 2008). The trees and shrubs, usually developing above the earth mounds, normally have an average height of 3 to 6 meters; all plants species in this formation being exclusive to the Cerrado biome (Araujo Neto et al., 1989).

The Cerrado *sensu stricto* is characterized by small trees with tortuous stems, rough bark and thick leaves (Fig. 12). In addition, the Cerrado *sensu stricto* presents an herbaceous layer that suffers with drought during the dry season, recovering fast during the wet season. The most common woody species colonizing this vegetation type are *Aspidospermum tomentosum*, *Bowdichia virgilioides*, *Byrsonima coccolobifolia*, *Caryocar brasiliense*, *Casearia silvestris*, *Connarus suberosus*, *Davilla elliptica*, *Dimorphandra mollis*, *Eriotheca gracilipes*, *Erythroxylum suberosum*, *Himathantus obovatus*, *Hymanea stignocarpa. Kielmeyera coriacea*, *Ouratea hexasperma Qualea grandiflora*, *Qualea multiflora*, *Qualea parviflora*, *Xylopia aromatica*, among others (Ratter *et al* (1996).

Figure 12. Cerrado *sensu stricto* formation during the dry season, Transect 3. Picture taken by the author, 08/2014.

2.5 Site selection and characteristics

Chosen for investigation were four transects with three different Cerrado vegetation subtypes: the gallery forest, the *cerrado sensu stricto*, and the *campo de murundus* (Fig.13). The transects were established along a gradient with vegetation in the riparian zone, according to groundwater table depth and distance from the river. Further riparian zone characteristics are shown in the Table 1.

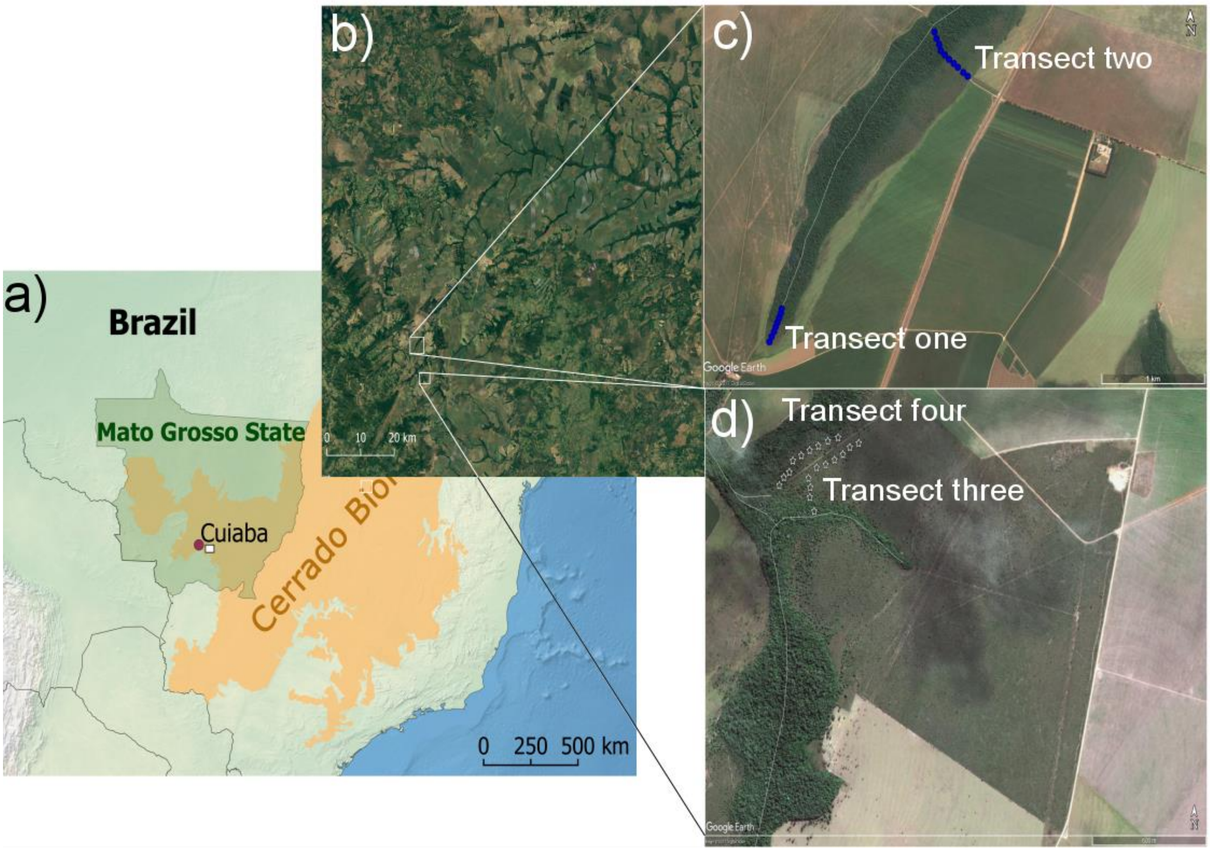

Figure 13. Depiction of the study area and transects. A) The study region, indicating the Cerrado biome, the city of Cuiabá and the state of Mato Grosso. B) The land-cover of the region and outline of the two farms. C) The study region itself, with Transects one and two, marked in blue, which show the locations of the groundwater wells; the white line indicates the river D) Further two transects; white stars mark the 10 vegetation plots in each, but not groundwater wells. River also depicted with a white line. Map sources: A) naturalearthdata.com & Ministry of Environment, Brazil; B-C-D) Google Maps.

Table 1. Summary of riparian zone areas.

	Riparian zone			
	Transect one	Transect two	Transect three	Transect four

	(fig. 14)	(fig. 15)	(fig. 16)	(fig. 17)
Farm	Santa Luzia	Santa Luzia	Rancho do Sol	Rancho do Sol
Latitude	-15.44’29”03°	-15.43’13”87°	-15.79’40”09°	-15.79’31”37°
Longitude	-55.21”46”77°	-55.20’40”41°	-55.33’70”85°	-55.33’89”85°
Vegetation	Gallery forest and *campo de murundus*	Gallery forest and *campo de murundus*	Gallery forest and Cerrado *sensu stricto*	Gallery forest and Cerrado *sensu stricto*
Number of plots	8 plots numbered from 1 (closest to the river) to 8 (farthest from the river)	10 plots numbered from 9 (closest to the river) to 18 (farthest from the river)	10 plots numbered from 19 (closest to the river) to 28 (farthest from the river)	10 plots numbered from 29 (closest to the river) to 38 (farthest from the river)
Total length of the transects	400 meters	1000 meters	1000 meters	1000 meters

On the Santa Luzia farm, the plots were 50 meters apart in Transect 1, because the riparian zone here was narrower than in the other areas of the study; the plots in Transect 2 and in the Cerrado’s transects were 100 meters apart. The plots were located at different distances from the river due to variations in the levels of the groundwater table, as our aim was to capture a gradient of groundwater level with the different plant species adapted to these environmental conditions. Moreover, the selected areas were established at sites previously authorized by the farmers for the investigations by the Carbiocial project.

The study region is part of the Cerrado biome, which stretches across (sub)tropical South America, near Cuiabá, the capital city of Mato Grosso. The land-cover of the region is dominated by agricultural fields (light greens) with remnants of natural Cerrado vegetation restricted to the riparian zones along the river networks (dark green branching). The study region itself is a part of the riparian zone embedded in the agricultural lands.

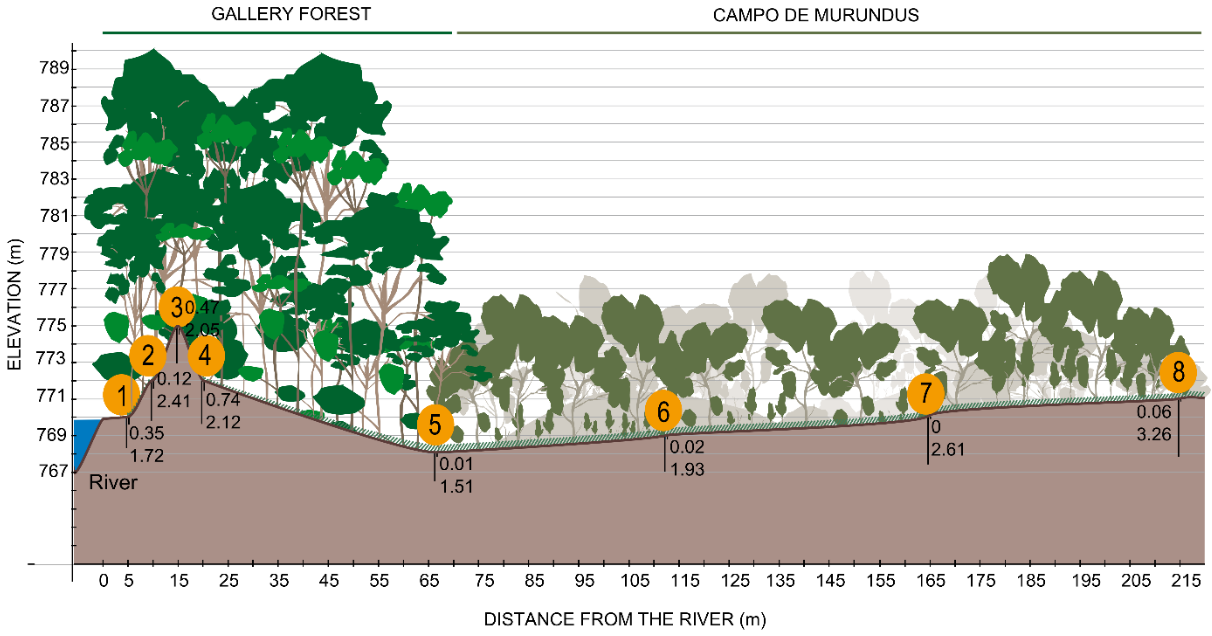

Figure 14. Transect 1 sketch. The x axis represents the distance from the river for each plot (meters) and the y axis the elevation of each plot (meters). The plots in the transect are indicated by numbers 1-8 in the yellow circles. The numbers in black indicate the average minimum and maximum groundwater depth for each well during the two years of sampling.

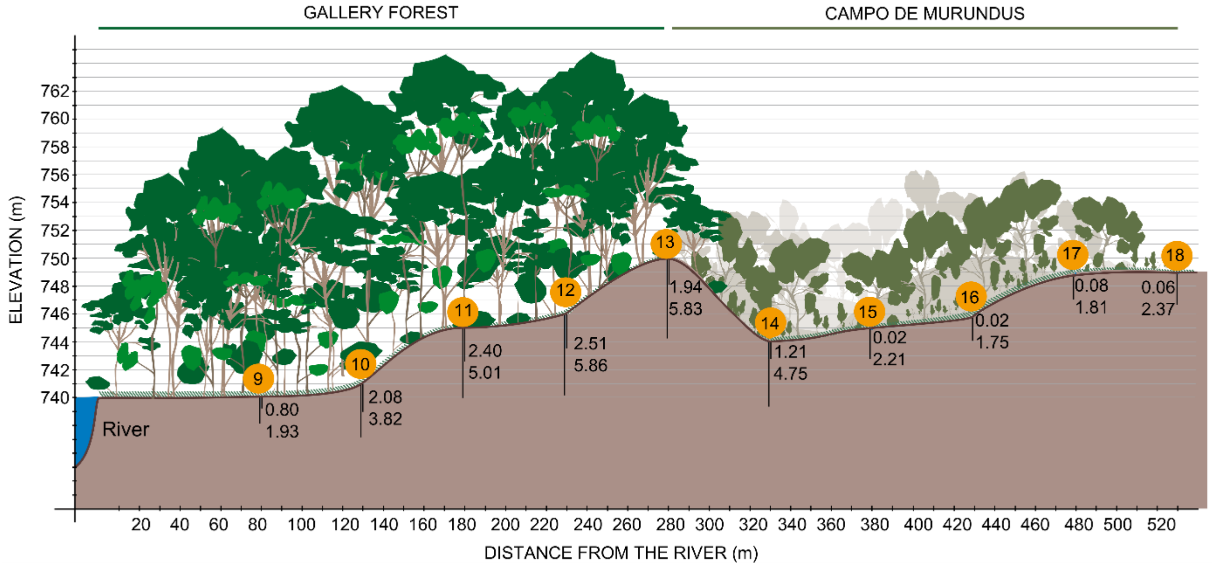

Figure 15. Transect 2 sketch. The x axis represents the distance from the river for each plot (meters), and the y axis is the elevation of each plot (meters). The plots in the transect are indicated by numbers 9-18 in the yellow circles. The numbers in black indicate the average minimum and maximum groundwater depth for each well during the two years of sampling.

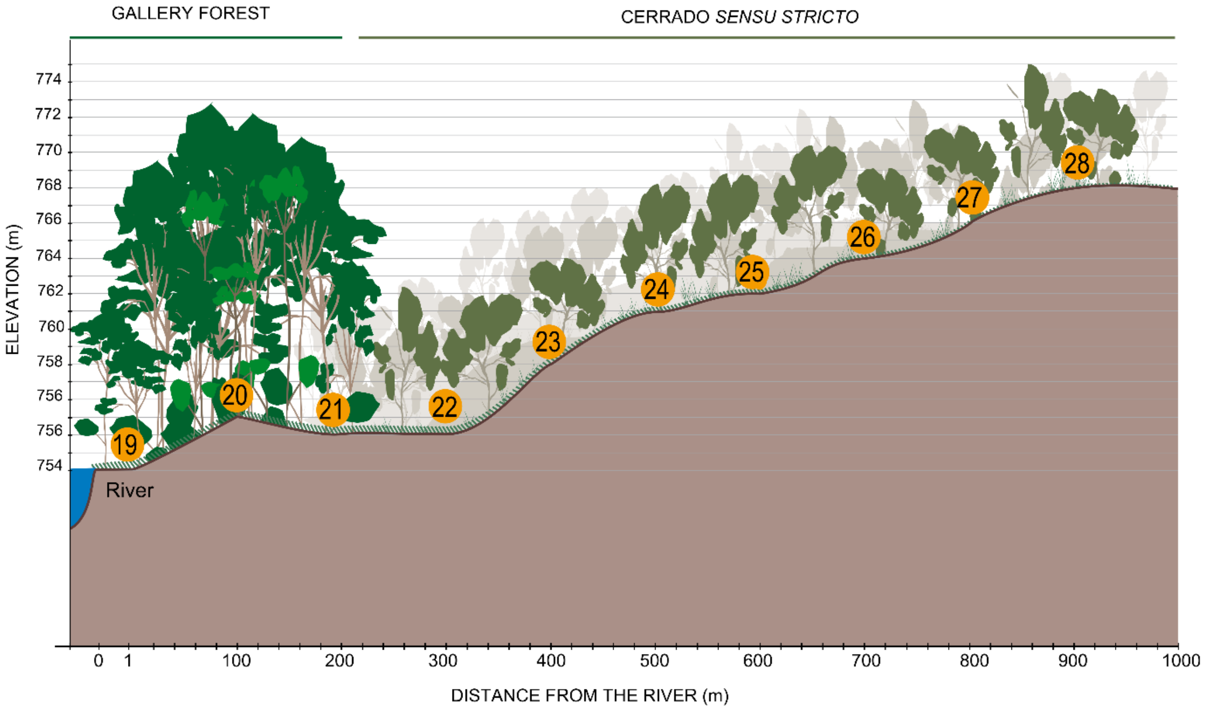

Figure 16. Transect 3 sketch. The x axis represents the distance from the river for each plot (meters), and the y axis is the elevation of each plot (meters). The plots in the transect are indicated by numbers 29-38 in the yellow circles.

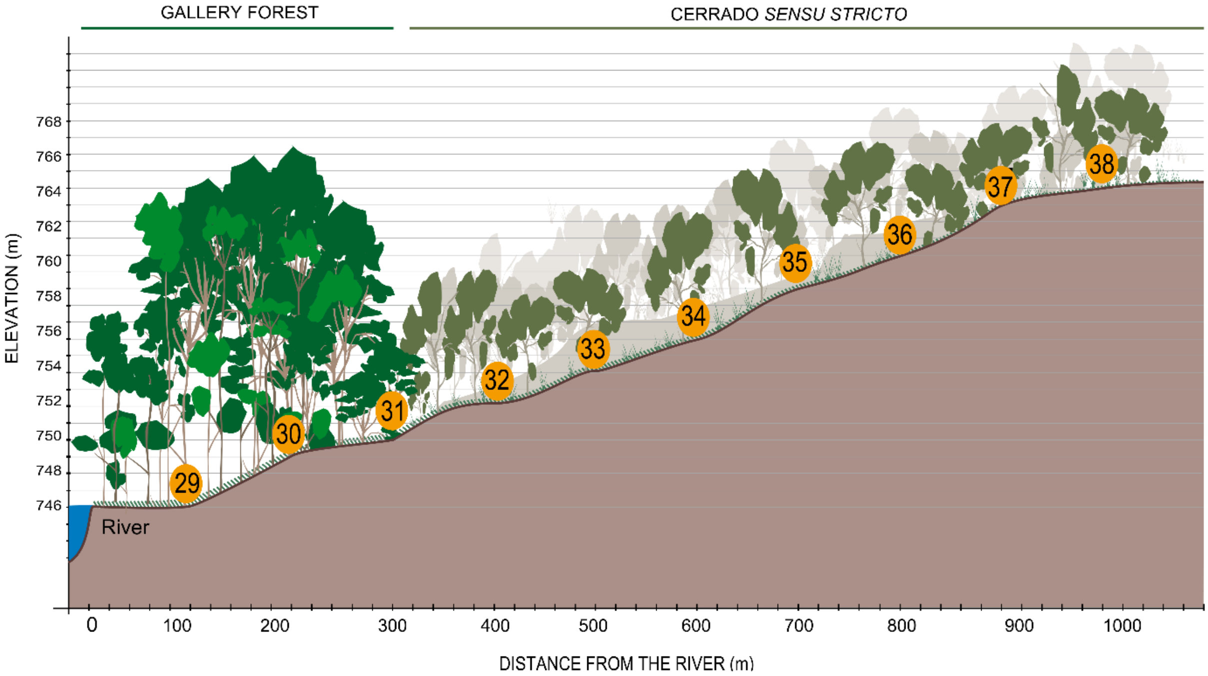

Figure 17. Transect 4 sketch.The x axis represents the distance from the river for each plot (meters), and the y axis is the elevation of each plot (meters). The plots in the transect are indicated by numbers 29-38 in the yellow circles.

3. Materials and methods

3.1 Overview

This research was conducted within the framework of the Carbiocial project (Carbon-optimized land management strategies for southern Amazonia), a collaborative research project (www.carbiocial.de) between several German universities and the Brazilian Federal University of Mato Grosso (UFMT). It was funded by the German Federal Ministry for Education and Research (BMBF). Carbiocial was an umbrella project that encompassed fourteen sub-projects (so-called SPs), with the SP-01 (Soil Degradation and Catchment Hydrology) as one of them. SP01 was directed by the Department of Landscape Ecology/University of Göttingen and collected a set of complete hydrological and meteorological data from 2013 until 2016. The present research was conducted from 2014 until 2016 as a part of SP01, acquiring plant floristic and phytosociological data, as well as hydrological indicators from two riparian zones in the Cerrado of Mato Grosso state (see chapter 2. Fig. 11). The general aim of this thesis has been to investigate the relation between plant diversity and hydrological indicators (groundwater level. This chapter describes the instruments and techniques adopted to achieve this research aim.

3.1.1 Vegetation phytosociology and floristics

With the aim of investigating their plant diversity, four land transects were defined and spatially delimited (see chapter 2. Fig. 11). Based on previous vegetation studies (Felfili, Nascimento, Fagg, & Meirelles, 2007), 38 plots 30x20m in size were delimited inside the land transects. A total of 22,800 square meters were surveyed, including 11 plots inside the gallery forest formation (4 in the first transect, 5 in the second, 1 in the third and 1 in the fourth), 9 plots inside the *campo de murundus* formation (4 on transect one and 5 on transect 2), and 20 plots inside the *cerrado sensu stricto* formation (10 on the third transect and 10 in the fourth transect) (see Fig. 12, 13, 14, 15 in chapter 2).

In keeping with the standard inclusion criteria of floristics and phytosociological studies (Philip, 1994), each tree or shrub in the gallery forest and *campo de murundus* with a diameter at breast height (DBH) of at least 15.5 cm (at 1.30 cm above ground for the gallery forest and 0.30 cm above ground for the *campo de murundus*) was documented. The selected trees and shrubs were also measured for their height (H). Most of the plant species were identified and catalogued in the field (type and frequency for each plot). The specimens that could not be categorized *in locu* were photographed, and their leaves, flowers or fruits were collected, pressed and dried, and later brought for analysis to the Herbarium of Mato Grosso State University in Nova Xavantina. The phytosociological and floristics survey was carried out between the months of February and August of 2014, and taxonomic data and biogeographic information from Forzza et al (2010) was used additionally.

Based on the plant information collected in the field, the plant dataset was further analyzed for its species composition and horizontal structure using descriptive phytosociological parameters (Curtis and McIntosh, 1951; Simpson, 1949; Shannon & Weiner, 1963; Mueller-Dombois & Ellenberg, 1974). These parameters include frequency, density, basal area, dominance, value index importance and index cover value of a species. The parameter “frequency” describes the degree of distribution of individual species in a community and is expressed in terms of percentage. It can be absolute, characterized by the proportion of plots sampled where the species occurs divided by the total plots sampled; or relative, defined by degree of diffusion of individual species in a defined area in relation to the number of all species that occurred in it. The density or abundance can be absolute, characterized by the number of individuals of the species per sampled unit; or relative, namely the number of species related to the total number of individual of all the species. The basal area is used to estimate the dominance of trees in a defined area of vegetation. The dominance also presents two distinct parameters, with the absolute being the sum of basal area of a species divided by the sum of all individual’s species occurring in all plots, expressed in square meters; and the relative being the coverage value of a species divided by the sum of coverage of the others species in the study area. The importance value index (IVI) represents the general impact of each species in the community structure. The importance cover value (IVC) is characterized by the cover impact of each species in the community structure. Their formulas are described below:

$$\boldsymbol{Absolute\ Frequency}\ (\%) = \frac{Number\ of\ plots\ in\ which\ species\ occurred}{Total\ number\ of\ plots\ studied} \times 100$$

$$\boldsymbol{Relative\ Frequency} = \frac{Density\ of\ the\ species}{Total\ frequency\ of\ all\ species} \times 100$$

$$\boldsymbol{Absolute\ Density} = \frac{Total\ number\ of\ individuals\ of\ the\ species}{Sample\ unit\ (m2)}$$

$$\boldsymbol{Relative\ Density}(\%)\ = \frac{Total\ number\ of\ individuals\ of\ the\ species}{Total\ density\ of\ all\ species} \times 100$$

$$\boldsymbol{Basal\ area}\ = \frac{(GBH)^2}{4\pi}$$

$$\boldsymbol{Absolute\ dominance} = \frac{G}{ha}$$

$$\boldsymbol{Relative\ Dominance} = \frac{Sum\ of\ basal\ area\ of\ all\ individuals\ of\ a\ species\ in\ a\ sample}{Total\ basal\ area\ of\ all\ species\ in\ the\ sample} \times 100$$

$$\boldsymbol{Importance\ Value\ Index} = Relative\ frequency\ \times relative\ density\ \times relative\ basal\ area$$

$$\boldsymbol{Index\ Cover\ Value} = Relative\ density\ \times relative\ dominance$$

Floristic richness and diversity were also surveyed, in order to characterize the type of vegetation and what plant communities were established in the study area, based on the plant lists (Nagendra, 2002). The most used indexes to quantify the α-diversity in a landscape are the Shannon and the Simpson indexes (Nagendra, 2002). The α-diversity can be defined as the species richness of a community (Whittaker, 1972). The Shannon and Simpson indexes are used to quantify the biodiversity of a community; they take into consideration the number of total species existing in it, as well as the abundance of each species present in this locus. The Simpson index reflects dominance: it defines the common and dominant species of an area, and is especially sensitive to capturing species dominance. Shannon’s index, on the other hand, captures the richness factor and species rarity. Shannon’s index highlights the richness factor of diversity; in contrast, Simpson’s index emphasizes the evenness aspect and is a measure of the equality of abundances in a community (Nagendra, 2002). These plant biodiversity indexes (α) were calculated for each one of the 38 plots. Plant diversity was estimated per plot using Shannon’s index or Shannon’s diversity, represented as H’ (described in equation 1), and the Simpson’s dominance or Simpson’s diversity index, represented as D (described in equation 2). The equations proposed by Shannon (1948) and Simpson (1949) for the indexes estimation are stated below:

Equation 1: $H' = - \sum p_i \ln p_i$

Equation 2: $D = \sum \frac{n_i(n_i-1)}{N(N-1)}$

p*i* = is the proportion p*i* = n*i*/N, where ni is the number of individuals in species *i*, and N is the total number of individuals in the community.

n*i* = is the total number of individuals of a particular species *i*.

N = the total number of the individuals in the community.

Shannon’s diversity presents typical values between 1.5 and 3.5 in most of the ecosystems (MacDonald, 2003), and rarely exceeds 4.0 (Margalef, 1972). Simpson’s index has values ranging between zero and one, where numbers closer to zero indicate to a higher diversity (Magurran and Dornelas, 2010).

3.1.2 Monitoring of groundwater levels

The groundwater level was monitored in 18 wells located in both vegetation types at Transects 1 and 2 (Fig. 18, 19, 20, 21, and 22). Due to technical problems, i.e. the soil and substrate in the *cerrado sensu stricto* was too compact to be manually drilled and machine drilling would have destroyed the vegetation, Transects 3 and 4 had no wells. The wells were a distance of 50 meters apart in Transect 1 (8 wells, numbered 1 to 8), and 100 meters apart in Transect 2 (10 wells, numbered 9 to 18), distributed along territorial patches of 400 m and 1000 m in length respectively. The difference in the lengths of these transects was due to the width of the riparian zones in the different areas along the stream. The wells were dug by hand with a metal driller, drilling down until reaching the groundwater level (figure 20). The groundwater measures were conducted with a well whistle attached to a matching tape (Brunnen model). Groundwater levels were measured twice a month during the data collection time period (2 years, from August 2014 to September 2016, covering two dry and two wet seasons). Groundwater water table depth was recorded in the field and entered in a table according to well number and date.

Figure 18. Well in the gallery forest of Transect 2. Picture taken by Tulio Santos, 02/2015.

Figure 19. Well in the *campo de murundus* of Transect 1, showing the waterlogged conditions during the wet season. Picture taken by Tulio Santos, 02/2015.

Figure 20. Groundwater well in the c*ampo de murundus* formation of Transect 1 (dry season). Picture taken by the author, 08/2014.

Figure 21. Groundwater well in the *campo de murundus* formation of Transect 2. Picture taken by the author, 08/2014.

Figure 22. Preparing the wells with the plastic tubes and fine netting. Picture taken by the author, 02/2014.

3.1.3 Water nutrient analyses

Water nutrient samples were taken with two main goals. First, we aimed to compare the nutrient concentration between areas outside and inside an intact riparian zone. Second, we wanted to discover if the nutrient concentration in the groundwater of a riparian zone could be an indicator for plant diversity and plant distribution in the Cerrado ecosystem. The sampled area represented the riparian zone (gallery forest and *campo de murundus*) and the cropland surrounding it. The following hydrological parameters were measured: overflow or surface runoff (Hortonian overflow or saturated runoff on soil surface) from cropland and riparian zone; stormflow (direct river runoff, part of discharge above baseflow); the streamflow (total discharge); and the groundwater.

The stormflow and overflow were collected during storm events, and stormflow with automatic water samplers (BL2000®, Hach-Lange GmbH, Germany) installed at the outlet of the catchment (20 cm water depth). The sampling procedure was both time- and stormflow-programmed. The time sampling routine involved filling a 1-litre water bottle daily, this being composed of 200 ml of water extracted at intervals of 4 hours and 48 minutes. The stormflow sampling involved a sub-hourly routine and was activated by the detection of a water level increase by means of a pressure bell switch (FD-01, Profimess GmbH, Germany). The automatic samplers were programmed to sample according to the stream stormflow pattern, by means of both hydrograph characteristics and the average water level change observed in field visits during the wet season. The time of every sampling procedure was logged and compared to the respective hydrograph, to verify whether the sampling procedure covered the respective total stormflow event, or if it needed adjustments due to the variations in seasonal flow.

Overland flow samples were obtained by using overland flow detectors (OFDs, Elsenbeer and Vertessy 2000; Kirkby et al. 1976), consisting of a 50-mm-diameter PVC tube with a detector section with 5-mm holes, connected at a right angle by a T-joint to a reservoir section tube with a 200-mL capacity. The contact of the detector section with the soil canalized/diverted the collected overland flow into the reservoir tube. Eight OFDs were placed inside of the gallery forest and ten OFDs in the cropland area surrounding the gallery forest; these were organized into flowlines identified in the field during the wet season.

The groundwater samples were taken from eight different wells located 50 meters apart along the 400-m-long riparian zone (Transect 1). The study design allowed a gradient of the ground water level from *campo de murundu*s to the gallery forest. The first well was located at the border of the stream, while the last one was located at the edge of the cropland and towards the vegetation (Fig. 12 and 13 from Chapter 2).

The samples were analyzed in the laboratory for total carbon (TC), total inorganic carbon (TIC), total organic carbon (TOC), dissolved carbon (DC), dissolved inorganic carbon (DIC) and dissolved organic carbon (DOC) using high temperature catalytic oxidation (TC-Analyzer, DIMATOC 100, Dimatec GmbH, Germany). Total nitrogen bound (TN_b) was quantified using the chemiluminescence detection method (DIMA_N, Dimatec GmbH, Germany). Cl^-, SO_4^{2-}, and F^- concentrations were determined by using ion chromatography (761 Compact IC, Metrohm, Switzerland), and Al^{3+}, Ca^{2+}, K^+, Mg^{2+}, Na^+, Si^{+4}, P, S, and Fe concentrations were quantified using atomic spectroscopy (ICP-OES, Optima 4300™ DV, PerkinElmer, Germany). After being collected, the containing bottles each automatic sampler were replaced by bottles pre-washed with distilled water. The collected samples were transferred to a 100-mL aliquot in sterilized bottles. For the dissolved solutes analyses, water was filtered through membrane filters with a pore size of 0.45 µm (cellulose acetate, Sartorius

Stedim Biotech GmbH, Germany). To conserve the chemical properties of the water after collection, samples were deep-frozen until their respective laboratory analysis.

3.1.4 Data analyses

For the phytosociological and floristic survey, descriptive statistics were collated to estimate plant distribution, and the structure and composition of the communities. The formulas of the indexes described in this methods section were applied to the dataset.

To understand how the riparian zones are related to water quality in the Cerrado, null significance hypothesis testing was applied to the dependent variable (water quality) measured at different sites. On the Santa Luzia farm, the water quality was determined based on overflow, stream flow, stormflow, and groundwater measurements during March 2014. For this, nutrient concentrations were compared using the nonparametric Mann-Whitney U test for non-normal distributions to determine whether the results were significantly different. The significance threshold was set at .05.

To analyze the relations between riparian zone vegetation, groundwater level and groundwater nutrient content, the normality of the distribution of Shannon's index, Simpson's index, groundwater level and groundwater nutrients were tested with the Shapiro-Wilk procedure (Shapiro and Wilk, 1965). The groundwater depth and groundwater nutrient distribution time-series were pooled plot-wise, and their variation was compared within and between transects (independent samples) with the Kruskall-Wallis test. The Bonferroni correction for multiple comparisons was applied to the alpha level. When significant, the plots were paired and compared post-hoc with the Mann-Whitney test. The significance threshold was set at 0.05. The dataset analysis was conducted with the software R (R Development Core Team, 2017).

To estimate possible relations between plant diversity, groundwater fluctuation and nutrient contents, compositional changes were analyzed by ordination in the vegetation plots along the transects. Detrended correspondence analysis (DCA) was applied, assuming a unimodal response of species to gradients. In a next step, we clustered plots into vegetation groups by running the *kmeans*-algorithm with their ordination coordinates (scores). The differentiation into vegetation groups was analyzed by relating environmental variables to the DCA result. This was done for each variable by fitting the vector in the ordination space that showed maximal correlation with the environmental values. Specifically, variables describing groundwater level dynamics and biogeochemical composition of groundwater were used. Further, two variables were added which represented the spatial location of the plots at the transect: the distance to the river and the relative elevation to the first plot next to the river. Before fitting the environmental vector, variables which correlated with one of the ordination axes were pre-selected. The fitting procedure is based on permutations which were constrained to each transect. In order to obtain an objective grouping of the vegetation plots, they were clustered according to their scores with the *kmeans* algorithm. The Calinski criterion was used for the optimal number of clusters to achieve best partitioning (Calinski and Harabasz, 1974). Ordination and clustering were conducted by using the software R (R Development Core Team, 2017) and its extension package ‘vegan’ (Oksanen, 2017).

Apart from the compositional changes in vegetation, we were interested in single species that are strongly associated with the determined vegetation groups. To assess the strength of species association, a statistical indicator value was calculated according to De Cáceres, Legendre, & Moretti (2010) and their R-package ‘indicspecies’. It is based on two probabilities: the first, *P (A)*, quantifies the probability of a plot belonging to a certain group, given that the target species is present. The second, *P(B)*, describes the relative frequency of the target species in plots of the focused group (De Cáceres et al., 2010). A permutation test allows for statistical inference on the associations.

4. Results

4.1 Phytosociology and floristic composition in the riparian zone (*campo de murundus, cerrado stricto sensu* and gallery forest)

4.1.1 *Campo de murundus* floristic composition and phytosociology

The survey of *campo de murundus* vegetation formation presented a total of 706 individuals, distributed among 32 families, 46 genera and 64 species. Only five individuals could not be fully identified; for one only the family category, and for four individuals only the genus could be determined (Table 2). Dead plants represented 13.17% of the absolute density and 9.57% of the basal area. Taking into account only the *campo de murundus* plots, Shannon's index (H') and Simpson's index (D) were respectively 3.68 and 0.63 for Transect 1 (plots 5–8), and 3.36 and 0.90 for Transect 2 (plots 14-18). The six species with the greatest absolute density represented 57.79% of all the sampled individuals (including the dead individuals), *Tibouchina stenocarpa* being the most abundant, dead individuals no identified, *Maprounea guianensis, Xylopia aromatica, Simarouba amara* and *Byrsonima clausseniana* (Table 2). Fourteen species were represented by only one individual (1.84%), and eleven species were characterized by two (3.12%), both together coming to 4.96% of the total sampled individuals (Table 2). Table A.1 (Appendices) show the distribution of plant species per plot in the *campo de murundus.*

Table 2. Species and phytosociological parameters of the *campo de murundus* plots (5-8, 14-18), Transect 1 and 2. AD = absolute density (individuals/ha), RD = relative density (%), AF = absolute frequency (% of plots at which a species occurs), RF = relative frequency (frequency of a species/sum frequency of all species)×100, Ado = absolute dominance, RDo = relative dominance (%), IVI = importance value index, and IVC = cover value index.

	Species	**AD**	**RD**	**AF**	**RF**	**ADo**	**RDo**	**IVI**	**IVC**
1.	*Tibouchina stenocarpa*	161	22.80	77.78	4.12	5.30	17.13	44.05	39.93
2.	Dead individuals	93	13.17	100	5.29	2.93	9.46	27.93	22.63
3.	*Maprounea guianensis*	46	6.51	88.89	4.71	1.65	5.34	16.56	11.86
4.	*Xylopia aromatica*	41	5.80	88.89	4.71	0.98	3.17	13.68	8.98
5.	*Simarouba amara*	34	4.82	44.44	2.35	1.52	4.92	12.09	9.74
6.	*Byrsonima clausseniana*	33	4.67	100	5.29	2.73	8.82	18.79	13.50
7.	*Tachigali vulgaris*	27	3.82	77.78	4.12	3.67	11.86	19.80	15.69
8.	*Miconia albicans*	21	2.97	88.89	4.71	0.27	0.87	8.55	3.84
9.	*Vismia guianensis*	17	2.41	11.11	0.59	0.39	1.26	4.26	3.67

10.	*Miconia cuspidata*	15	2.12	66.67	3.53	0.47	1.54	7.19	3.66
11	*Emotum nitens*	11	1.56	44.44	2.35	0.65	2.10	6.01	3.66
12	*Pyptocarpha rotundifolia*	11	1.56	33.33	1.76	0.25	0.81	4.13	2.37
13	*Byrsonima pachyphylla*	10	1.42	22.22	1.18	0.27	0.88	3.47	2.30
14	*Alchornea schomburgkii*	9	1.27	33.33	1.76	1.13	3.66	6.70	4.93
15	*Ouratea hexasperma*	9	1.27	22.22	1.18	0.08	0.27	2.73	1.55
16	*Rapanea guianensis*	9	1.27	22.22	1.18	0.13	0.42	2.87	1.70
17	*Symplocos sp*	9	1.27	22.22	1.18	0.14	0.47	2.92	1.74
18	*Casearia arborea*	8	1.13	33.33	1.76	0.12	0.38	3.28	1.51
19	*Heteropterys byrsonimifolia*	8	1.13	33.33	1.76	0.32	1.04	3.93	2.17
20	*Myrtaceae*	8	1.13	22.22	1.18	0.32	1.05	3.36	2.18
21	*Tapirira obtusa*	8	1.13	22.2	1.18	0.32	1.04	3.35	2.17
22	*Myrcia splendens*	7	0.99	44.44	2.35	0.97	3.13	6.48	4.12
23	*Alibertia edulis*	6	0.85	44.44	2.35	0.44	1.43	4.64	2.28
24	*Nectandra cuspidata*	6	0.85	11.11	0.59	0.07	0.23	1.66	1.08
25	*Alchornea glandulosa*	5	0.71	33.33	1.76	0.10	0.34	2.81	1.05
26	*Connarus suberosus*	5	0.71	33.33	1.76	0.07	0.23	2.70	0.94
27	*Eriotheca gracilipes*	5	0.71	22.22	1.18	0.19	0.62	2.51	1.33
28	*Erythroxilum egleri*	5	0.71	11.11	0.59	0.18	0.58	1.88	1.29
29	*Psidium sp*	5	0.71	33.33	1.76	0.09	0.30	2.77	1.00
30	*Qualea dichotoma*	5	0.71	22.22	1.18	0.14	0.44	2.33	1.15
31	*Virola sebifera*	5	0.71	22.22	1.18	0.18	0.57	2.45	1.28
32	*Byrsonima laxiflora*	4	0.57	22.22	1.18	0.12	0.40	2.14	0.96
33	*Macairea cf pachyphylla*	4	0.57	33.33	1.76	0.03	0.11	2.44	0.68
34	*Onychopetalum amazonicum*	4	0.57	33.33	1.76	0.35	1.12	3.45	1.69
35	*Qualea grandiflora*	4	0.57	11.11	0.59	2.63	8.52	9.67	9.08
36	*Cybianthus detergens*	3	0.42	11.11	0.59	0.03	0.11	1.12	0.54
37	*Kielmeyera coriacea*	3	0.42	33.33	1.76	0.12	0.39	2.58	0.81
38	*Siparuna guianensis*	3	0.42	22.22	1.18	0.03	0.11	1.71	0.54
39	*Styrax ferrugineus*	3	0.42	22.22	1.18	0.10	0.33	1.93	0.76
40	*Banisteriopsis sp*	2	0.28	22.22	1.18	0.03	0.11	1.57	0.39
41	*Bocageopsis mattogrossensis*	2	0.28	11.11	0.59	0.04	0.14	1.01	0.42
42	*Davilla elliptica*	2	0.28	11.11	0.59	0.06	0.18	1.06	0.47
43	*Diplopterys lucida*	2	0.28	22.22	1.18	0.03	0.08	1.54	0.37
44	*Eugenia chrysantha*	2	0.28	11.11	0.59	0.06	0.19	1.06	0.47
45	*Guatteria scytophylla*	2	0.28	11.11	0.59	0.03	0.09	0.97	0.38
46	*Myrcia guianensis*	2	0.28	22.22	1.18	0.07	0.24	1.70	0.52
47	*Myrsine coriacea*	2	0.28	11.11	0.59	0.03	0.09	0.96	0.37
48	*Ocotea velloziana*	2	0.28	33.33	1.76	0.04	0.14	2.19	0.42
49	*Tapirira guianensis*	2	0.28	11.11	0.59	0.67	2.16	3.03	2.44
50	*Vismia augusta*	2	0.28	11.11	0.59	0.01	0.04	0.92	0.33
51	*Aspidosperma macrocarpum*	1	0.14	11.11	0.59	0.01	0.04	0.77	0.18
52	*Bowdichia virgilioides*	1	0.14	11.11	0.59	0.02	0.07	0.80	0.21
53	*Connarus perrottetii*	1	0.14	11.11	0.59	0.01	0.03	0.76	0.17
54	*Heteropterys mircini*	1	0.14	11.11	0.59	0.02	0.08	0.80	0.22

55	*Hirtella glandulosa*	1	0.14	11.11	0.59	0.04	0.13	0.86	0.27
56	*Ilex sp*	1	0.14	11.11	0.59	0.02	0.06	0.79	0.20
57	*Lacistema aggregatum*	1	0.14	11.11	0.59	0.01	0.04	0.77	0.18
58	*Miconia ferruginata*	1	0.14	11.11	0.59	0.02	0.07	0.80	0.21
59	*Nectandra hihua*	1	0.14	44.44	2.35	0.03	0.11	2.60	0.25
60	*Physocalymma scaberrima*	1	0.14	11.11	0.59	0.02	0.05	0.78	0.19
61	*Qualea parviflora*	1	0.14	11.11	0.59	0.06	0.19	0.92	0.33
62	*Roupala montana*	1	0.14	11.11	0.59	0.01	0.03	0.76	0.17
63	*Vismia macrophylla*	1	0.14	11.11	0.59	0.04	0.13	0.86	0.27
64	*Vismia amazonica*	1	0.14	11.11	0.59	0.01	0.04	0.77	0.18
	Total	706	100	1888.89	100	30.93	100	300	200

The most abundant botanical families were the *Malpighiaceae*, the *Melastomataceae* and the *Myrtaceae*, totaling 40.22% of all sampled individuals. The botanical families with the highest quantity of species, in decreasing order, were the *Melastomataceae, Euphorbiaceae, Annonaceae, Simaroubaceae,* and *Malpighiaceae*, contributing with 44.62% of the total species (Table 2) sampled. The total basal area was 5.67 m²/ha. The species with highest basal areas were *Tibouchina stenocarpa* (DoR = 17.13%), *Tachigali vulgaris* (11.86%), dead individuals (9.46%), *Byrsonima clausseniana* (8.82%), *Qualea grandiflora* (8.52%), *Maprounea guianensis* (5.34%), and *Simarouba amara* (4.92%), adding up to 66.05% of the total basal area, and representing 66.05% of total relative dominance (Table 2). The seven species with the highest importance value index (IVI) came to 50.97% of the total IVI, and the 7 species with highest cover value index (IVC) represented 65.70%, including the dead individuals. The species with the highest values for IVI and IVC, in decreasing order, were *Tibouchina stenocarpa*, dead individuals no identified, *Tachigali vulgaris, Byrsonima clausseniana*, *Maprounea guianensis, Xylopia aromatica,* and *Simarouba amara*.

The most constant species in the sampling were *Byrsonima clausseniana* (RF = 5.29%), dead individuals (RF = 5.29%), *Maprounea guianensis* (RF = 4.71%), *Xylopia aromatica* (RF = 4.71%), *Miconia albicans* (RF = 4.71%), *Tibouchina stenocarpa* (RF = 4.12%), *Tachigali vulgaris* (RF = 4.12%), and *Miconia cuspidata* (RF = 3.53%). Amongst the most important species, the *Tachigali vulgaris* and the *Maprounea guianensis* are the highest trees in the *campo de murundus*, with some specimens reaching up to 10 meters. In contrast, all the trees of the *Tibouchina stenocarpa*, *Byrsonima clausseniana, Xylopia aromatica,* and *Simarouba amara* were respectively under 6 meters, 7.7 meters, 7.5 meters, and 9 meters.

The phytogeographic characteristics of the sample showed five plant species exclusive to *campo de murundus* (type of *cerrado*): *Byrsonima clausseniana, Heteropterys byrsonimifolia, Styrax ferrugineus, Ouratea hexasperma,* and *Tibouchina stenocarpa* (Table 3 and Fig. 23). Four other plant species that are native to the Amazon rainforest are *Connarus perrottetii, Guatteria scytophylla, Onychopetalum amazonicum,* and *Tibouchina stenocarpa.* Further plant species whose normal distribution ranges in both the Cerrado and Amazon biomes are *Alibertia edulis, Byrsonima pachyphylla, Erythroxilum egleri, Lacistema aggregatum, Macairea pachyphylla, Piptocarpha rotundifolia, Vismia amazonica,* and *Xylopia aromatica.* Other species have a more generalist distribution, spreading also into the Atlantic rainforest these include *Alchornea schomburgkii, Bocageopsis mattogrossensis, Casearia arborea, Cybianthus detergens, Davilla elliptica, Maprounea guianensis, Miconia cuspidata, Tapirira obtusa, Virola sebifera.* Moreover, several plant species can also survive in the Caatinga, Pantanal, or Pampas, such as *Alchornea glandulosa, Aspidosperma macrocarpum, Bowdichia virgilioides, Connarus suberosus, Myrcia guianensis, Myrcia splendens, Qualea grandiflora, Qualea parviflora,* and *Tapirira guianensis.* The plant species' phytogeographic domains thus demonstrate that Amazon rainforest and Atlantic rainforest species infiltrate this formation type.

Table 3. Plant species sampled in the *campo de murundus* plots (5-8, 14-18), Transect 1 and 2, and their respective occurrence in the phytogeographic domains. AMR = Amazon rainforest, CAA= Caatinga, CER = Cerrado, ATR = Atlantic rainforest, PAN = Pantanal, PAM = Pampas. The species in bold indicate plants exclusive to *campo de murundus* (type of cerrado).

Botanical Family	**Species *campo de murundus***	**Phytogeographic domains**
Euphorbiaceae	*Alchornea glandulosa*	AMR, CAA, CER, ATR
Euphorbiaceae	*Alchornea schomburgkii*	AMR, CER, ATR
Rubiaceae	*Alibertia edulis*	AMR, CER
Apocynaceae	*Aspidosperma macrocarpum*	AMR, CAA, CER, ATR
Malpighiaceae	*Banisteriopsis sp*	AMR, CAA, CER, ATR
Annonaceae	*Bocageopsis mattogrossensis*	AMR, CER, ATR
Fabaceae	*Bowdichia virgilioides*	AMR, CAA, CER, ATR, PAN
Malpighiaceae	***Byrsonima clausseniana***	CER
Malpighiaceae	*Byrsonima laxiflora*	CER, ATR, PAN
Malpighiaceae	*Byrsonima pachyphylla*	AMR, CER
Salicaceae	*Casearia arborea*	AMR, CER, ATR
Primulaceae	*Cybianthus detergens*	AMR, CER, ATR
Connaraceae	*Connarus perrottetii*	AMR
Connaraceae	*Connarus suberosus*	AMR, CAA, CER, ATR, PAN
Dilleniaceae	*Davilla elliptica*	AMR, CER, ATR

Malpighiaceae	*Diplopterys lucida*	AMR, ATR
Icacinaceae	*Emotum nitens*	AMR, CAA, CER, ATR
Malvaceae	*Eriotheca gracilipes*	AMR, CAA, CER
Erythroxylaceae	*Erythroxilum egleri*	AMR, CER
Myrtaceae	*Eugenia chrysantha*	-
Annonaceae	*Guatteria scytophylla*	AMR
Malpighiaceae	**Heteropterys byrsonimifolia**	CER
Malpighiaceae	*Heteropterys nitida*	CER, ATR
Chrysobalanaceae	*Hirtella glandulosa*	AMR, CAA, CER
Aquifoliaceae	*Ilex sp*	AMR, CAA, CER, ATR
Calophyllaceae	*Kielmeyera coriacea*	AMR, CAA, CER, ATR
Lacistemataceae	*Lacistema aggregatum*	AMR, CER
Melastomataceae	*Macairea pachyphylla*	AMR, CER
Euphorbiaceae	*Maprounea guianensis*	AMR, CER, ATR
Melastomataceae	*Miconia albicans*	AMR, CAA, CER, ATR
Melastomataceae	*Miconia cuspidata*	AMR, CER, ATR
Melastomataceae	*Miconia ferruginata*	AMR, CAA, CER
Myrtaceae	*Myrcia guianensis*	AMR, CAA, CER, ATR, PAN
Myrtaceae	*Myrcia splendens*	AMR, CAA, CER, ATR, PAN
Primulaceae	*Myrsine coriacea*	CER, ATR
Lauraceae	*Nectandra cuspidata*	AMR, CAA, CER
Lauraceae	*Nectandra hihua*	AMR, CER, ATR, PAN
Lauraceae	*Ocotea velloziana*	CAA, CER, ATR
Annonaceae	*Onychopetalum amazonicum*	AMR
Ochnaceae	**Ouratea hexasperma**	CER
Lythraceae	*Physocalymma scaberrima*	-
Myrtaceae	*Psidium sp*	AMR, CAA, CER, ATR, PAN
Vernonieae	*Piptocarpha rotundifolia*	AMR, CER
Vochysiaceae	*Qualea dichotoma*	CAA, CER, ATR
Vochysiaceae	*Qualea grandiflora*	AMR, CAA, CER, ATR
Vochysiaceae	*Qualea parviflora*	AMR, CAA, CER, ATR
Primulaceae	*Rapanea guianensis*	AMR, CAA, CER, ATR
Proteaceae	*Roupala montana*	AMR, CAA, CER, ATR
Simaroubaceae	*Simarouba amara*	AMR, CAA, CER, ATR
Siparunaceae	*Siparuna guianensis*	AMR, CAA, CER, ATR, PAN
Styracaceae	**Styrax ferrugineus**	CER
Symplocaceae	*Symplocos sp*	AMR, CAA, CER, ATR, PAM
Fabaceae	*Tachigali vulgaris*	AMR, CAA, CER, ATR, PAN
Anacardiaceae	*Tapirira guianensis*	AMR, CAA, CER, ATR, PAN, PAM
Anacardiaceae	*Tapirira obtusa*	AMR, CER, ATR
Melastomataceae	**Tibouchina stenocarpa**	CER
Myristicaceae	*Virola sebifera*	AMR, CER, ATR
Hypericaceae	*Vismia amazonica*	AMR, CER
Hypericaceae	*Vismia augusta*	AMR, ATR
Hypericaceae	*Vismia guianensis*	AMR, CAA, CER, ATR

Hypericaceae	*Vismia macrophylla*	AMR, ATR
Annonaceae	*Xylopia aromatica*	AMR, CER

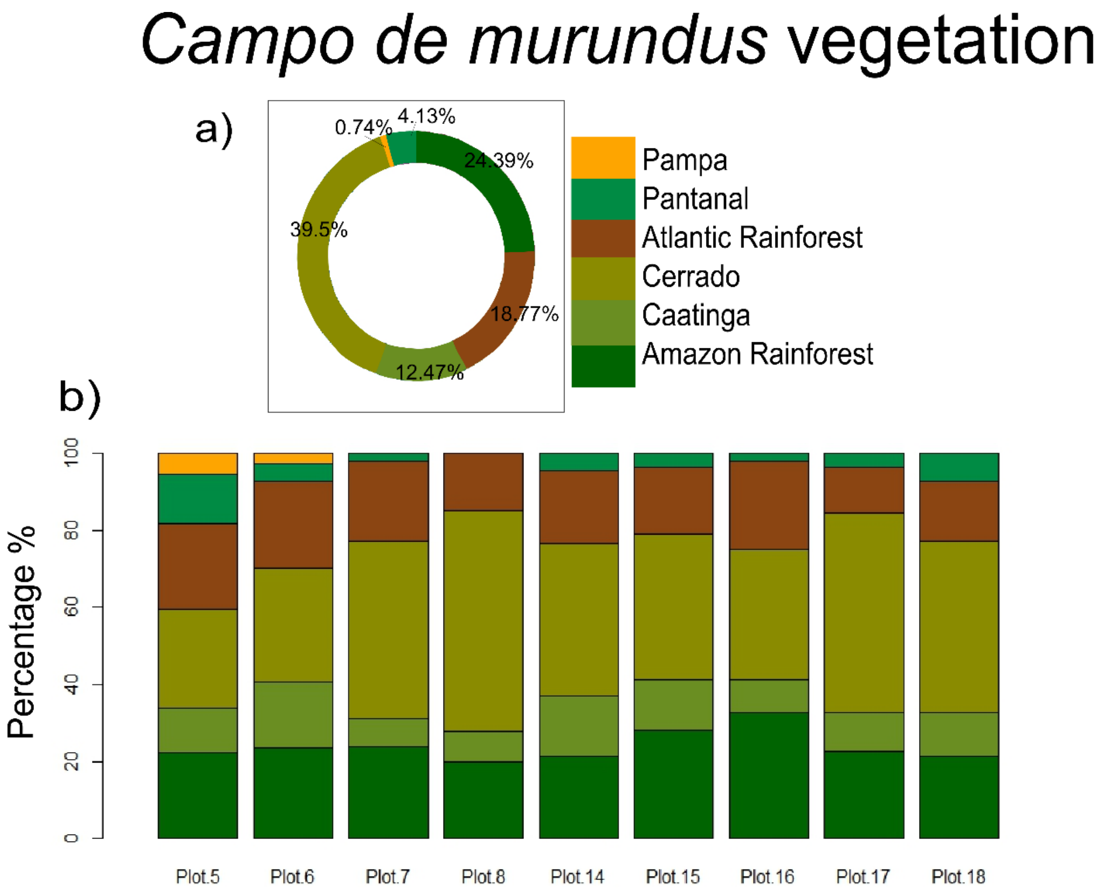

Figure 23. a) Percentage of the represented phytogeographic domains in *campo de murundus* vegetation b) assemblage and phytogeographic distribution of the surveyed plant species in plots (5-8) and (14-18).

4.1.2 *Cerrado stricto sensu* floristic and phytosociology

A total of 1937 individual were sampled in the *cerrado stricto sensu* plots (Transects 3 and 4, plots 20-28, 30-38). They were distributed among 35 families, 62 genera and 99 species. Seven could not be fully identified, six could only be assisgned to their genera and one was completely unidentified (Table 4). Dead individuals represented 2.42% of the total density and 4.15% of the basal area. The Shannon’s index (H’) and Simpson’s index (D) were 3.25 and 0.95 respectively in Transect 3 (plots 19-28), and 3.46 and 0.95 in Transect 4 (plots 29-38). The six species with the greatest absolute density represented 42.38% of all sampled individuals, *Roupala montana* being the most abundant, followed by *Davilla elliptica*, *Cybianthus detergens*, *Kielmeyera coriacea*, *Qualea parviflora* and *Ouratea hexasperma* (Table 4). Twenty-seven species were represented by only one individual (1.39%), and eleven by only two (0.57%), adding up to 2.01% of the total sample (Table 4). Table A.2 (Appendices) show the distribution of plant species per plot in the *cerrado stricto sensu.*

Table 4. Species and phytosociological parameters of the *cerrado strictu sensu*, Transects 3 and 4 (plots 19-38). AD = absolute density (individuals/ha), relative density (%), RD = relative density (%), AF = absolute frequency (% of plots at which a species occurs), RF = relative frequency (frequency of a species/sum frequency of all species) ×100, Ado = absolute dominance, RDo = relative dominance (%), IVI = importance value index, and IVC = cover value index.

	Species Cerrado	**AD**	**RD**	**FA**	**FR**	**Ado**	**Rdo**	**IVI**	**IVC**
1.	*Roupala montana*	167	8.62	94.44	3.26	3.05	6.76	18.64	15.38
2.	*Davilla elliptica*	164	8.47	94.44	3.26	3.50	7.76	19.49	16.23
3.	*Cybianthus detergens*	149	7.69	94.44	3.26	2.34	5.19	16.14	12.88
4.	*Kielmeyera coriacea*	125	6.45	88.89	3.07	2.42	5.36	14.88	11.81
5.	*Qualea parviflora*	113	5.83	88.89	3.07	1.63	3.61	12.51	9.44
6.	*Ouratea hexasperma*	103	5.32	94.44	3.26	1.63	3.62	12.20	8.93
7.	*Myrcia dealbata*	90	4.65	66.67	2.30	3.21	7.11	14.06	11.76
8.	*Myrcia rostrata*	86	4.44	72.22	2.50	1.22	2.71	9.65	7.15
9.	*Qualea grandiflora*	73	3.77	72.22	2.50	1.53	3.40	9.66	7.17
10.	*Byrsonima pachyphylla*	66	3.41	66.67	2.30	1.42	3.15	8.86	6.56
11.	*Tachigali vulgaris*	61	3.15	83.33	2.88	5.76	12.77	18.80	15.92
12.	Dead individuals	47	2.43	83.33	2.88	1.94	4.29	9.60	6.72
13.	*Psidium sp*	43	2.22	94.44	3.26	0.89	1.97	7.45	4.19
14.	*Caryocar brasiliense*	39	2.01	55.56	1.92	0.98	2.17	6.10	4.18
15.	*Byrsonima coccolobifolia*	36	1.86	83.33	2.88	0.60	1.33	6.07	3.19
16.	*Eriotheca gracilipes*	35	1.81	55.56	1.92	0.80	1.78	5.51	3.59
17.	*Bowdichia virgilioides*	28	1.45	55.56	1.92	0.57	1.26	4.62	2.70
18.	*Myrcia splendens*	24	1.24	27.78	0.96	0.54	1.20	3.40	2.44
19.	*Erythroxilum egleri*	23	1.19	50.00	1.73	0.42	0.93	3.85	2.12
20.	*Dimorphandra mollis*	22	1.14	61.11	2.11	0.51	1.14	4.39	2.27
21.	*Mouriri elliptica*	22	1.14	55.56	1.92	0.39	0.86	3.91	1.99
22.	*Piptocarpha rotundifolia*	22	1.14	61.11	2.11	0.85	1.88	5.13	3.02
23.	*Styrax ferrugineus*	21	1.08	33.33	1.15	0.89	1.98	4.22	3.06
24.	*Andira cuyabensis*	19	0.98	55.56	1.92	0.33	0.73	3.63	1.71
25.	*Pouteria torta*	19	0.98	44.44	1.54	0.34	0.76	3.27	1.74
26.	*Stryphnodendron rotundifolium*	17	0.88	66.67	2.30	0.34	0.76	3.94	1.64
27.	*Emmotum nitens*	16	0.83	38.89	1.34	0.46	1.02	3.19	1.84
28.	*Pouteria ramiflora*	16	0.83	38.89	1.34	0.38	0.85	3.02	1.67
29.	*Tabebuia aurea*	16	0.83	50.00	1.73	0.28	0.63	3.18	1.45
30.	*Handroanthus ochraceus*	15	0.77	55.56	1.92	0.32	0.72	3.41	1.49
31.	*Miconia ferruginata*	14	0.72	27.78	0.96	0.40	0.88	2.56	1.60

32.	*Diospyros hispida*	13	0.67	44.44	1.54	0.13	0.28	2.49	0.95
33.	*Hymenaea stignocarpa*	13	0.67	38.89	1.34	0.21	0.46	2.48	1.13
34.	*Qualea multiflora*	13	0.67	33.33	1.15	0.19	0.43	2.25	1.10
35.	*Handroanthus chrysothichus*	12	0.62	33.33	1.15	0.28	0.61	2.38	1.23
36.	*Kielmeyera sp*	12	0.62	16.67	0.58	0.21	0.47	1.66	1.09
37.	*Miconia albicans*	12	0.62	44.44	1.54	0.13	0.29	2.44	0.91
38.	*Connarus suberosus*	10	0.52	38.89	1.34	0.11	0.24	2.10	0.76
39.	*Salacia crassifolia*	9	0.46	38.89	1.34	0.17	0.38	2.19	0.85
40.	*Guapira noxia*	8	0.41	27.78	0.96	0.35	0.78	2.16	1.20
41.	*Heteropterys byrsonimifolia*	8	0.41	16.67	0.58	0.23	0.51	1.50	0.93
42.	*Plathymenia reticulata*	8	0.41	27.78	0.96	0.22	0.48	1.85	0.89
43.	*Aspidosperma macrocarpum*	7	0.36	33.33	1.15	0.13	0.29	1.80	0.65
44.	*Erythroxilum tortuosum*	6	0.31	27.78	0.96	0.09	0.20	1.47	0.51
45.	*Vochysia rufa*	6	0.31	33.33	1.15	0.08	0.17	1.63	0.48
46.	*Xylopia aromatica*	6	0.31	22.22	0.77	0.14	0.30	1.38	0.61
47.	*Buchenavia tomentosa*	5	0.26	22.22	0.77	0.18	0.40	1.43	0.66
48.	*Kielmeyera rubriflora*	5	0.26	11.11	0.38	0.07	0.16	0.80	0.42
49.	*Lafoensia pacari*	5	0.26	16.67	0.58	0.09	0.19	1.02	0.45
50.	*Miconia humilis*	5	0.26	11.11	0.38	0.09	0.19	0.83	0.45
51.	*Pterodon pubescens*	5	0.26	11.11	0.38	0.77	1.70	2.34	1.95
52.	*Sthrychnos guianensis*	5	0.26	5.56	0.19	0.07	0.14	0.59	0.40
53.	*Macherium opacum*	4	0.21	22.22	0.77	0.09	0.20	1.17	0.41
54.	*Tachigali subvelutinum*	4	0.21	11.11	0.38	0.10	0.23	0.82	0.44
55.	*Couepia grandiflora*	3	0.15	5.56	0.19	0.06	0.14	0.49	0.29
56.	*Eugenia aurata*	3	0.15	11.11	0.38	0.04	0.08	0.62	0.24
57.	*Maprounea guianensis*	3	0.15	5.56	0.19	0.09	0.21	0.55	0.36
58.	*Mouriri pusa*	3	0.15	11.11	0.38	0.04	0.09	0.63	0.24
59.	*Myrcia sp*	3	0.15	16.67	0.58	0.03	0.07	0.80	0.22
60.	*Annona crassifolia*	2	0.10	5.56	0.19	0.05	0.11	0.40	0.21
61.	*Aspidosperma tomentosum*	2	0.10	11.11	0.38	0.02	0.04	0.52	0.14
62.	*Erythroxilum suberosum*	2	0.10	5.56	0.19	0.02	0.04	0.33	0.14
63.	*Eugenia chrysantha*	2	0.10	11.11	0.38	0.02	0.05	0.54	0.16
64.	*Himatanthus sucuuba*	2	0.10	11.11	0.38	0.05	0.11	0.59	0.21
65.	*Leptolobium dasycarpum*	2	0.10	5.56	0.19	0.02	0.04	0.33	0.14
66.	*Dyrcia sp*	2	0.10	5.56	0.19	0.00	0.00	0.30	0.10
67.	*Plenckia populnea*	2	0.10	5.56	0.19	0.03	0.07	0.37	0.18
68.	*Rapanea guianensis*	2	0.10	11.11	0.38	0.03	0.06	0.55	0.17
69.	*Tapirira guianensis*	2	0.10	11.11	0.38	0.01	0.02	0.51	0.12
70.	*Tapirira obtusa*	2	0.10	5.56	0.19	0.05	0.12	0.41	0.22
71.	*Ardisia lhotskyana*	1	0.05	5.56	0.19	0.01	0.03	0.27	0.08
72.	*Agonandra brasiliense*	1	0.05	5.56	0.19	0.01	0.02	0.26	0.07
73.	*Alchornea speciosa*	1	0.05	5.56	0.19	0.02	0.05	0.29	0.10
74.	*Bauhinia sp*	1	0.05	5.56	0.19	0.01	0.02	0.27	0.08

75.	*Brosimum gaudichaudii*	1	0.05	5.56	0.19	0.01	0.03	0.28	0.08
76.	*Byrsonima arthropoda*	1	0.05	5.56	0.19	0.02	0.04	0.29	0.10
77.	*Byrsonima basiloba*	1	0.05	5.56	0.19	0.02	0.05	0.29	0.10
78.	*Dalbergia miscolobium*	1	0.05	5.56	0.19	0.01	0.03	0.27	0.08
79.	*Eremanthus mattogrossensis*	1	0.05	5.56	0.19	0.03	0.06	0.30	0.11
80.	*Ficus sp*	1	0.05	5.56	0.19	0.01	0.02	0.27	0.08
82.	*Heteropterys coriaceae*	1	0.05	5.56	0.19	0.01	0.02	0.26	0.07
83.	*Himatanthus obovata*	1	0.05	5.56	0.19	0.01	0.02	0.26	0.07
84.	*Leptolobium nitens*	1	0.05	5.56	0.19	0.01	0.02	0.26	0.07
85.	*Licania humiles*	1	0.05	5.56	0.19	0.01	0.02	0.26	0.07
86.	*Machaerium myrianthum*	1	0.05	5.56	0.19	0.01	0.03	0.27	0.08
87.	*Miconia brevipes*	1	0.05	5.56	0.19	0.01	0.02	0.26	0.07
88.	*Myrcia bella*	1	0.05	5.56	0.19	0.01	0.03	0.28	0.08
89.	*Myrcia crisantha*	1	0.05	5.56	0.19	0.01	0.03	0.28	0.08
90.	*NI*	1	0.05	5.56	0.19	0.02	0.04	0.28	0.09
91.	*Ocotea cf velloziana*	1	0.05	5.56	0.19	0.02	0.04	0.29	0.09
92.	*Ocotea acutangula*	1	0.05	5.56	0.19	0.01	0.03	0.28	0.08
93.	*Schefflera macrocarpa*	1	0.05	5.56	0.19	0.02	0.04	0.28	0.09
94.	*Schefflera malmei*	1	0.05	5.56	0.19	0.01	0.02	0.27	0.08
95.	*Siparuna guianensis*	1	0.05	5.56	0.19	0.01	0.02	0.26	0.07
96.	*Sthrychnos pseudochina*	1	0.05	5.56	0.19	0.01	0.02	0.27	0.07
97.	*Tabebuia ochracea*	1	0.05	5.56	0.19	0.08	0.17	0.41	0.22
98.	*Tachigali velutinus*	1	0.05	5.56	0.19	0.04	0.10	0.34	0.15
99.	*Vochysia sp*	1	0.05	5.56	0.19	0.03	0.07	0.32	0.12
		1937	100	2894.44	100	45	100	300	200

The most abundant botanical families were *Myrtaceae, Proteaceae, Dilleniaceae, Primulaceae, Calophylaceae, Vochysiaceae, Lauraceae,* contributing 51.76% to the total of sampled individuals. The botanical families that showed the highest quantity of species, in decreasing order, were *Fabaceae*, *Myrtaceae*, *Melastomataceae*, and *Malpighiaceae,* representing 38% of the total sampled species (Table 4). The total basal area was 4.32 m^2/ha. The species with the highest basal areas were *Tachigali vulgaris* (Rdo = 12.77%), *Davilla elliptica* (Rdo = 7.76%), *Myrcia dealbata* (Rdo = 7.11%), *Roupala montana* (Rdo = 6.76%), and *Kielmeyera coriacea* (DoR = 5.36%), adding up to 14.44% of the total basal area, and representing 39.76% of the total relative dominance (Table 4). The eight species with the highest importance value index (IVI) came to 107.92% of the total IVI, and the eight species with the highest cover value index (IVC) represented 86.43%. The species with the highest values for IVI and IV, in a decreasing order, were *Davilla elliptica, Tachigali vulgaris,* *Roupala montana, Cybianthus detergens, Kielmeyera coriacea, Myrcia dealbata, Qualea parviflora,* and *Ouratea hexasperma.*

The most predominant species in the sample were *Byrsonima pachyphylla* (3.30%), *Roupala montana* (RF = 3.26%), *Davilla elliptica* (RF = 3.26%), *Cybianthus detergens* (RF = 3.26%), *Ouratea hexasperma* (RF = 3.26%), *Psidium* sp. (3.26%), *Kielmeyera coriacea* (3.07%), *Tachigali vulgaris* (2.88%), dead individuals (2.88%), *Byrsonima coccolobifolia* (2.88%), *Qualea parviflora* (2.50%), *Myrcia rostrata* (2.50%), *Qualea grandiflora* (2.50%), and *Myrcia dealbata* (2.30%). The highest trees amongst the most important species were *Tachigali vulgaris*, *Roupala montana,* and *Kielmeyera coriacea*, reaching up to 12 meters. In contrast, all the trees of *Davilla elliptica*, *Cybianthus detergens*, *Myrcia dealbata*, *Qualea parviflora*, *Ouratea hexasperma,* were respectively under 2.7 meters, 2.5 meters, 5.5 meters, 3.8 meters, and 2.8 meters in height.

Species belonging exclusively to the Cerrado biome included *Byrsonima basiloba, Erythroxylum tortuosum, Guapira noxia, Kielmeyera rubriflora, Lafoensia pacari, Myrcia bella, Myrcia crulsiana, Myrcia dealbata, Ouratea hexasperma, Pouteria torta, Styrax ferrugineus, Tachigali subvelutina,* and *Vochysia rufa.* However, it was clear from the phytogeographic characteristics of the plant species found in our survey of the *cerrado stricto sensu* that Amazon and Atlantic rainforest species also infiltrate this type of formation (Table 5 and Fig. 24). We recognized two plants species native to the Amazon rainforest, *Leptolobium nitens* and *Machaerium myrianthum.* In addition, we also found generalist plant species that occur in both formations, such as *Andira cujabensis, Aspidosperma macrocarpum, Aspidosperma tomentosum, Byrsonima arthropoda, Byrsonima pachyphylla, Eremanthus mattogrossensis, Erythroxilum engleri, Erythroxilum suberosum, Himathanthus sucuubus, Leptolobium dasycarpum, Licania humiles, Miconia brevipes, Schefflera malmei,* and *Xylopia aromatica.* In addition, we found plants species with a more generalistic distribution that also colonize the Atlantic rainforest, such as *Byrsonima coccolobifolia, Cybianthus detergens, Davilla elliptica, Euplassa inaequalis, Tachigali vulgaris, Tapirira obtusa.* Moreover, we found that several other plant species can survive in the Caatinga, Pantanal and Pampas biomes, such as *Agonandra brasiliensis, Annona crassifolia, Bowdichia virgilioides, Brosimum gaudichaudii, Connarus suberosus, Dalbergia miscolobium, Diospyros hispida, Heteropterys byrsinomifolia,* and *Myrcia splendens.*

Table 5. The plant species sampled in the *cerrado stricto sensu* plots (20-28, 30-38), Transects 3 and 4, and their respective occurrence phytogeographic domains. AMR = Amazon rainforest, CAA= Caatinga, CER = Cerrado, ATR = Atlantic rainforest, PAN =

Pantanal, PAM = Pampas. The species in bold indicate plants exclusive to *cerrado stricto sensu* vegetation form.

Botanical family	***Species***	Phytogeographic domains
Opiliaceae	*Agonandra brasiliensis*	AMR, CAA, CER, ATR, PAN
Fabaceae	*Andira cujabensis*	AMR, CER
Annonaceae	*Annona crassifolia*	AMR, CAA, CER, ATR, PAN
Primulaceae	*Ardisia lhotskyana*	-
Apocynaceae	*Aspidosperma macrocarpum*	AMR, CAA, CER, ATR
Apocynaceae	*Aspidosperma tomentosum*	AMR, CER
Fabaceae	*Bauhinia sp*	AMR, CAA, CER, ATR, PAN, PAM
Fabaceae	*Bowdichia virgilioides*	AMR, CAA, CER, ATR, PAN
Moraceae	*Brosimum gaudichaudii*	AMR, CAA, CER, ATR, PAN
Combretaceae	*Buchenavia tomentosa*	AMR, CAA, CER, ATR
Malpighiaceae	*Byrsonima arthropoda*	AMR, CER
Malpighiaceae	***Byrsonima basiloba***	CER
Malpighiaceae	*Byrsonima coccolobifolia*	AMR, CER, ATR
Malpighiaceae	*Byrsonima pachyphylla*	AMR, CER
Caryocaraceae	*Caryocar brasiliense*	AMR, CAA, CER, ATR
Connaraceae	*Connarus suberosus*	AMR, CAA, CER, ATR, PAN
Chrysobalanacae	*Couepia grandiflora*	AMR, CAA, CER
Primulacae	*Cybianthus detergens*	AMR, CER, ATR
Fabaceae	*Dalbergia miscolobium*	AMR, CAA, CER, ATR, PAN
Dilleniaceae	*Davilla elliptica*	AMR, CER, ATR
Fabaceae	*Dimorphandra mollis*	AMR, CAA, CER, ATR
Ebenaceae	*Diospyros hispida*	AMR, CAA, CER, ATR, PAN
Icacinaceae	*Emmotum nitens*	AMR, CAA, CER, ATR
Asteraceae	*Eremanthus mattogrossensis*	AMR, CER
Malvaceae	*Eriotheca gracilipes*	AMR, CAA, CER
Erythroxylaceae	*Erythroxilum engleri*	AMR, CER
Erythroxylaceae	*Erythroxilum suberosum*	AMR, CER
Erythroxylaceae	***Erythroxilum tortuosum***	CER
Myrtacae	*Eugenia aurata*	CAA, CER, ATR, PAN
Myrtacae	*Eugenia chrysantha*	-
Moraceae	*Ficus sp*	AMR, CAA, CER, ATR, PAN
Nyctaginaceae	***Guapira noxia***	CER
Apocynaceae	*Hanchornia speciosa*	AMR, CAA, CER, ATR
Bignoniaceae	*Handroanthus chrysotrichus*	CER, ATR
Bignoniaceae	*Handroanthus ochraceus*	AMR, CAA, CER, ATR
Malpighiaceae	*Heteropterys byrsonimifolia*	AMR, CER, ATR, PAN, PAM
Malpighiaceae	*Heteropterys coriacea*	CAA, CER
Apocynaceae	*Himatanthus obovatus*	AMR, CAA, CER
Apocynaceae	*Himatanthus sucuubus*	AMR, CER
Fabaceae	*Hymenaea stignocarpa*	AMR, CAA, CER, PAN
Calophyllaceae	*Kielmeyera coriacea*	AMR, CAA, CER, ATR
Calophyllaceae	***Kielmeyera rubriflora***	CER
Calophyllaceae	*Kielmeyera sp*	AMR, CAA, CER, ATR
Lythraceae	***Lafoensia pacari***	CER
Fabaceae	*Leptolobium dasycarpum*	AMR, CER
Fabaceae	*Leptolobium nitens*	AMR
Chrysobalanacae	*Licania humiles*	AMR, CER
Fabaceae	*Machaerium myrianthum*	AMR
Fabaceae	*Macherium opacum*	CAA, CER

Euphorbiaceae	*Maprounea guianensis*	AMR, CER, ATR
Arecaceae	*Mauritia flexuosa*	AMR, CAA, CER
Melastomataceae	*Miconia albicans*	AMR, CAA, CER, ATR
Melastomataceae	*Miconia brevipes*	AMR, CER
Melastomataceae	*Miconia ferruginata*	AMR, CER, CAA
Fabaceae	*Mimosia humilis*	-
Melastomataceae	*Mouriri elliptica*	AMR, CAA, CER, ATR
Melastomataceae	*Mouriri pusa*	AMR, CAA, CER
Myrtaceae	***Myrcia bella***	CER
Myrtaceae	***Myrcia crulsiana***	CER
Myrtaceae	***Myrcia dealbata***	CER
Myrtaceae	*Myrcia rostrata*	-
Myrtaceae	*Myrcia splendens*	AMR, CAA, CER, ATR, PAN
Myrtaceae	*Psidium sp*	AMR, CAA, CER, ATR, PAN
Lauraceae	*Ocotea velloziana*	CAA, CER, ATR
Lauraceae	*Ocotea acutangula*	-
Lauraceae	***Ouratea hexasperma***	CER
Asteraceae	*Piptocarpha rotundifolia*	AMR, CER
Fabaceae	*Plathymenia reticulata*	AMR, CAA, CER, ATR
Celastraceae	*Plenckia populnea*	AMR, CAA, CER, ATR
Sapotaceae	*Pouteria ramiflora*	AMR, CAA, CER, ATR
Sapotaceae	***Pouteria torta***	CER
Fabaceae	*Pterodon pubescens*	AMR, CAA, CER, PAN
Vochysiaceae	*Qualea grandiflora*	AMR, CAA, CER, ATR
Vochysiaceae	*Qualea multiflora*	AMR, CER, ATR
Vochysiaceae	*Qualea parviflora*	AMR, CAA, CER, ATR
Primulacae	*Rapanea guianensis*	AMR, CAA, CER, ATR
Proteaceae	*Roupala montana*	AMR, CAA, CER, ATR
Celastraceae	*Salacia crassifolia*	CAA, CER
Araliaceae	*Schefflera macrocarpa*	CAA, CER, ATR
Araliaceae	*Schefflera malmei*	AMR, CER
Siparunaceae	*Siparuna guianensis*	AMR, CAA, CER, ATR, PAN
Loganiaceae	*Strychnos guianensis*	AMR, ATR
Loganiaceae	*Strychnos pseudoquina*	CAA, CER, ATR, PAN
Fabaceae	*Stryphnodendron rotundifolium*	CAA, CER
Styracaceae	***Styrax ferrugineus***	CER
Bignoniaceae	*Tabebuia aurea*	AMR, CAA, CER, ATR, PAN
Bignoniaceae	*Tabebuia ochracea*	AMR, CAA, CER, ATR
Fabaceae	***Tachigali subvelutina***	CER
Fabaceae	*Tachigali vulgaris*	AMR, CER, ATR
Anacardiaceae	*Tapirira guianensis*	AMR, CAA, CER, ATR, PAN, PAM
Anacardiaceae	*Tapirira obtusa*	AMR, CER, ATR
Vochysiaceae	***Vochysia rufa***	CER
Annonaceae	*Xylopia aromatica*	AMR, CER

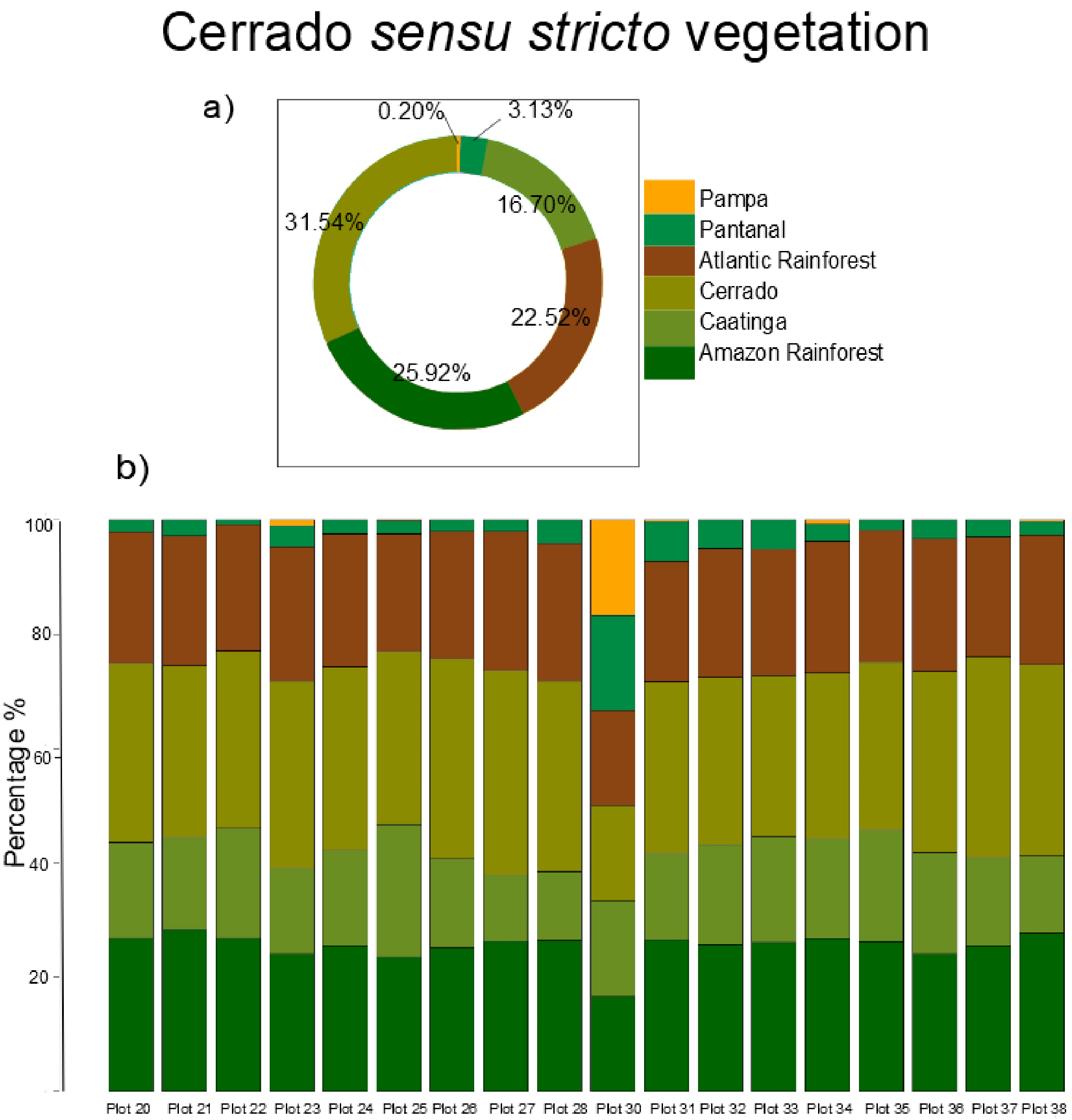

Figure 24. a) Percentage of the represented phytogeographic domains in *cerrado sensu stricto* vegetation b) assemblage and phytogeographic distribution of the surveyed plant species in plots (20-28) and (30-38).

4.1.3 Gallery forest: floristics and phytosociology

A total of 370 individuals were sampled in the gallery forest plots (Transects 1, 2, 3, 4; plots 1-4, 9-13, 19, 29). They were distributed among 34 families, 62 genera and 82 species. Four individuals could not be fully identified; of these three could only be assigned to their genera (Table 6). Dead individuals represented 5.95% of the total density and 7.43% of the basal area. The Shannon’s index (H`) and Simpson’s index (D) were 3.23 and 0.06 for Transect 3, and 3.48 and 0.04 for Transect 4, respectively. The eight species with the greatest absolute density represented 28.9% of all the sampled individuals, *Tapira obtusa* being the most abundant, followed by *Protium spruceanum, Nectandra cuspidata, Amaioua guianensis, Sacoglottis guianensis,* and *Cordia bicolor* (Table 6). Twenty-six species were represented by only one individual each (7.02%), and ten by two individuals (2.70%), amounting to 9.72% of the total sample (Table 6). Table A.3 (Appendices) show the distribution of plant species per plot in the gallery forest.

Table 6. Identified species of the gallery forest formation and their phytosociological parameters. AD = absolute density (individuals/ha), RD = relative density, AF = absolute frequency (% of plots at which a species occurs), RF = relative frequency (frequency of a species/sum frequency of all species) ×100, Ado = absolute dominance, RDo = relative dominance (%), IVI = importance value index, and IVC = cover value index.

	Species	**AD**	**RD**	**AF**	**RF**	**ADo**	**RDo**	**IVI**	**IVC**
1.	*Tapirira obtusa*	30	8.11	36.36	2.1	4.67	2.42	12.58	10.53
2.	Dead individuals	22	5.95	90.91	5.1	3.47	1.80	12.87	7.75
3.	*Protium spruceanum*	19	5.13	45.45	2.6	2.08	1.08	8.78	6.21
4.	*Nectandra cuspidata*	17	4.59	45.45	2.6	3.11	1.61	8.77	6.20
5.	*Amaioua guianensis*	16	4.32	27.27	1.5	1.58	0.82	6.68	5.14
6.	*Sacoglottis guianensis*	13	3.51	63.63	3.6	2.69	1.39	8.50	4.91
7.	*Cordia bicolor*	12	3.24	45.45	2.6	2.51	1.30	7.11	4.54
8.	*Inga vera*	10	2.70	36.36	2.1	1.16	0.60	5.35	3.30
9.	*Miconia sp*	10	2.70	27.27	1.5	0.53	0.84	5.08	3.55
10.	*Minquartia guianensis*	10	2.70	36.36	2.1	1.42	0.74	5.49	3.44
11.	*Miconia cuspidata*	9	2.43	27.27	1.5	2.90	1.50	5.47	3.93
12.	*Byrsonima chrysophylla*	8	2.16	45.45	2.6	1.35	0.70	5.43	2.86
13.	*Sloanea eichleri*	8	2.16	36.36	2.1	1.83	0.95	5.16	3.11
14.	*Inga pezizifera*	7	1.89	36.36	2.1	1.21	0.63	4.57	2.52
15.	*Miconia brevipes*	7	1.89	36.36	2.1	0.45	0.23	4.17	2.12
16.	*Mabea fistulifera*	6	1.62	36.36	2.1	0.50	0.26	3.93	1.88
17.	*Tapirira guianensis*	6	1.62	27.27	1.5	0.60	0.31	3.47	1.93
18.	*Xylopia amazonica*	6	1.62	9.09	0.5	0.37	0.19	2.32	1.81
19.	*Bocageopsis mattogrossensis*	5	1.35	27.27	1.5	0.53	0.27	3.16	1.62
20.	*Emotum nitens*	5	1.35	18.18	1	1.30	0.67	3.05	2.03
21.	*Micropholis guyanensis*	5	1.35	27.27	1.5	1.43	0.74	3.63	2.09
22.	*Myrsine coriacea*	5	1.35	18.18	1	0.69	0.36	2.73	1.71
23.	*Ocotea aciphylla*	5	1.35	18.18	1	0.89	0.46	2.84	1.81
24.	*Physocalymma scaberrima*	5	1.35	36.36	2.1	0.44	0.23	3.63	1.58
25.	*Protium pilosissimum*	5	1.35	27.27	1.5	0.35	0.18	3.07	1.53
26.	*Simarouba amara*	5	1.35	45.45	2.6	1.47	0.76	4.67	2.11
27.	*Kielmeyera sp*	4	1.08	9.09	0.5	0.44	0.23	1.82	1.31
28.	*Myrcia splendens*	4	1.08	18.18	1	0.47	0.24	2.35	1.32
29.	*Myrciaria dubia*	4	1.08	18.18	1	0.59	0.31	2.41	1.39
30.	*Ocotea leucoxylum*	4	1.08	36.36	2.1	0.74	0.38	3.51	1.46

31.	*Protium heptaphyllum*	4	1.08	36.36	2.1	0.31	0.16	3.29	1.24
32.	*Schefflera morototoni*	4	1.08	27.27	1.5	1.00	0.52	3.14	1.60
33.	*Tachigali vulgaris*	4	1.08	18.18	1	0.36	0.19	2.29	1.27
34.	*Xylopia polyantha*	4	1.08	9.09	0.5	0.36	0.19	1.78	1.27
35.	*Alchornea glandulosa*	3	0.81	18.18	1	0.96	0.49	2.33	1.31
36.	*Bellucia grossularioides*	3	0.81	18.18	1	0.63	0.32	2.16	1.13
37.	*Croton palanostigma*	3	0.81	27.27	1.5	0.13	0.07	2.42	0.88
38.	*Himatanthus articulatus*	3	0.81	18.18	1	0.50	0.26	2.09	1.07
39.	*Jacaranda copaia*	3	0.81	27.27	1.5	0.16	0.08	2.43	0.89
40.	*Licania kunthiana*	3	0.81	27.27	1.5	0.58	0.30	2.65	1.11
41.	*Micropholis venulosa*	3	0.81	18.18	1	0.19	0.10	1.93	0.91
42.	*Nectandra hihua*	3	0.81	27.27	1.5	2.21	1.14	3.49	1.95
43.	*Pouteria ramiflora*	3	0.81	27.27	1.5	0.28	0.14	2.49	0.95
44.	*Pseudolmedia laevigata*	3	0.81	27.27	1.5	0.27	0.14	2.49	0.95
45.	*Pseudolmedia laevis*	3	0.81	27.27	1.5	0.66	0.34	2.69	1.15
46.	*Qualea dichotoma*	3	0.81	9.09	0.5	0.50	0.26	1.58	1.07
47.	*Chaetocarpus echinocarpus*	2	0.54	18.18	1	1.79	0.93	2.50	1.47
48.	*Connarus perrottetii*	2	0.54	18.18	1	0.76	0.39	1.96	0.94
49.	*Ecclinusa ramiflora*	2	0.54	18.18	1	0.16	0.08	1.65	0.62
50.	*Guatteria foliosa*	2	0.54	18.18	1	0.15	0.08	1.64	0.62
51.	*Guatteria scytophylla*	2	0.54	18.18	1	0.17	0.09	1.65	0.63
52.	*Hydrochorea corymbosa*	2	0.54	9.09	0.5	0.47	0.24	1.29	0.78
53.	*Mauritia flexuosa*	2	0.54	9.09	0.5	1.13	0.59	1.64	1.13
54.	*Ocotea velloziana*	2	0.54	18.18	1	0.22	0.11	1.68	0.65
55.	*Ormosia paraensis*	2	0.54	18.18	1	0.15	0.08	1.65	0.62
56.	*Vismia macrophylla*	2	0.54	18.18	1	0.14	0.07	1.64	0.61
57.	*Alibertia edulis*	1	0.27	9.09	0.5	0.63	0.32	1.11	0.60
58.	*Apuleia leiocarpa*	1	0.27	9.09	0.5	0.07	0.04	0.82	0.30
59.	*Aspidosperma excelsum*	1	0.27	9.09	0.5	0.03	0.02	0.80	0.29
60.	*Aspidosperma desmanthum*	1	0.27	9.09	0.5	0.04	0.03	0.80	0.29
61.	*Bredemeyera lucida*	1	0.27	9.09	0.5	0.04	0.02	0.80	0.29
62.	*Buchenavia macrophylla*	1	0.27	9.09	0.5	0.16	0.08	0.86	0.35
63.	*Byrsonima arthropoda*	1	0.27	9.09	0.5	0.49	0.25	1.04	0.52
64.	*Casearia arborea*	1	0.27	9.09	0.5	0.04	0.02	0.80	0.29
65.	*Dacryodes microcarpa*	1	0.27	9.09	0.5	0.10	0.05	0.84	0.32
66.	*Diospyros sericea*	1	0.27	9.09	0.5	0.04	0.02	0.80	0.29
67.	*Enterolobium schomburgkii*	1	0.27	9.09	0.5	0.18	0.09	0.87	0.36
68.	*Ficus sp*	1	0.27	9.09	0.5	4.43	2.29	3.08	2.56
69.	*Handroantus impetiginosus*	1	0.27	9.09	0.5	0.13	0.07	0.85	0.34
70.	*Humiria balsamifera*	1	0.27	9.09	0.5	0.04	0.02	0.80	0.29
71.	*Lamanonia ternata*	1	0.27	9.09	0.5	0.11	0.06	0.84	0.33
72.	*Licania apetala*	1	0.27	9.09	0.5	0.77	0.40	1.18	0.67
73.	*Machaerium myrianthum*	1	0.27	9.09	0.5	0.61	0.31	1.10	0.59
74.	*Miconia egensis*	1	0.27	9.09	0.5	0.06	0.029	0.81	0.30
75.	*Myrcia amazonica*	1	0.27	9.09	0.5	0.03	0.02	0.80	0.29

76.	*Pouteria filipes*	1	0.27	9.09	0.5	0.36	0.18	0.97	0.45
77.	*Quiina cruegeriana*	1	0.27	9.09	0.5	0.08	0.04	0.82	0.31
78.	*Sparattosperma leucanthum*	1	0.27	9.09	0.5	0.05	0.02	0.81	0.30
79.	*Virola calophylla*	1	0.27	9.09	0.5	0.05	0.02	0.81	0.29
80.	*Virola sebifera*	1	0.27	9.09	0.5	0.13	0.07	0.85	0.34
81.	*Xylopia aromatica*	1	0.27	9.09	0.5	0.05	0.03	0.81	0.30
82.	*Xylopia chivantinensis*	1	0.27	9.09	0.5	0.03	0.02	0.80	0.29
	Total	370	100	1772.73	100	62.94	100	300	200

The most abundant botanical families were *Anacardiaceae, Lauraceae, Melastomataceae, Burseraceae* and *Fabaceae*, representing 41.62% of all sampled individuals. The botanical families exhibiting the highest number of species were, in decreasing order, *Annonaceae, Fabaceae, Lauraceae, Melastomataceae* and *Sapotaceae,* which together contributed 33.51% of the total species sampled (Table 6). The total basal area was 29.84 m²/ha. The species with largest basal areas were *Tapirira obtusa* (Rdo = 2.42%), *Nectandra cuspidata* (Rdo = 1.61%), *Miconia cuspidata* (Rdo = 1.50%), *Sacoglottis guianensis* (Rdo = 1.39%), *Cordia bicolor* (Rdo = 1.30%), and *Protium spruceanum* (Rdo = 1.08%), amounting to 9.06% of the total basal area, and representing 9.30% of total relative dominance (Table 6). The six species with the highest importance value index (IVI) represented 65.29% of the total IVI, and the six with the highest importance value cover (IVC) came to 45.28%, including the dead individuals. The species that presented the highest values for IVI and IV, in decending order, were *Tapira obtusa, Protium spruceanum, Nectandra cuspidata, Sacoglottis guianensis, Cordia bicolor,* and *Amaioua guianensis.*

The most constant plants in the sampling were dead individuals (RF = 5.1%), followed by *Sacoglottis guianensis* (RF = 3.6%), *Protium spruceanum* (RF = 2.6%), *Nectandra cuspidata* (RF = 2.6%), *Cordia bicolor* (RF = 2.6%), and *Byrsonima chrysophylla* (RF = 2.6%). Amongst the most important species, *Protium spruceanum, Nectandra cuspidata* and *Amaioua guianensis* were the highest trees in the gallery forest, with some trees reaching up to 10 meters. In addition, all the trees of *Tibouchina stenocarpa, Byrsonima clausseniana, Xylopia aromatica,* and *Simarouba amara* were 6 meters, 7.7 meters, 7.5 meters, and 9 meters, respectively.

The phytogeographic characterization of the surveyed plants showed the occurrence of plant species native to the Amazon biome, such as *Aspidosperma excelsum, Dacryodes microcarpa, Inga pezizifera, Croton palagostina, Pseudolmedia laevis, Jacaranda copaia, Ormosia paraensis,* and *Sacoglottis guianensis* (Table 7, Fig. 3.3). More broadly, we identified several plant species natively distributed in both the Cerrado and the Amazon rainforest, including *Alibertia edulis, Bellucia grossularioides, Byrsonima arthropoda, Bredemeyera lucida, Buchenavia macrophylla, Connarus perrottetii, Guatteria foliosa, Guatteria scytophylla, Protium pilosissimum, Minquartia guianensis, Himatanthus articulates, Hydrochorea corymbosa, Machaerium myrianthum. Miconia brevipes, Miconia egensis, Virola calophylla, Xylopia amazonica,* and *Xylopia polyantha.* In addition, plant species that also survive in the Atlantic rainforest were identified, such as *Amaioua guianensis, Bocageopsis mattogrossensis, Byrsonima chrysophylla, Casearia arborea, Licania apetala, Miconia cuspidata, Micropholis guyanensis, Micropholis venulosa, Myrcia amazonica, Ocotea aciphylla, Protium spruceanum, Pseudolmedia laevigata, Tapira obtusa,* and *Virola sebifera.* Additional plant species that develop in other Brazilian biomes, such as the Caatinga, Pantanal or Pampas, were also recognized in the gallery forest plots, such as *Apuleia leiocarpa, Handroantus impetiginosus, Myrcia splendens, Schefflera morototoni, Sparattosperma leucanthum, Tapirira guianensis.*

Table 7. The plant species sampled in the gallery forest, Transects 1, 2, 3, 4 (plots 1-4, 9-13, 19, 29), and their respective occurrence in phytogeographic domains. AMR = Amazon rainforest, CAA= Caatinga, CER = Cerrado, ATR = Atlantic rainforest, and PAN = Pantanal, PAM = Pampas.

Botanical families	***Species***	**Phytogeographic domains**
Euphorbiaceae	*Alchornea glandulosa*	AMR, CAA, CER, ATR
Rubiaceae	*Alibertia edulis*	AMR, CER
Rubiaceae	*Amaioua guianensis*	AMR, CER, ATR
Fabaceae	*Apuleia leiocarpa*	AMR, CAA, CER, ATR
Apocynaceae	*Aspidosperma excelsum*	AMR
Apocynaceae	*Aspidosperma desmanthum*	AMR, ATR
Melastomataceae	*Bellucia grossularioides*	AMR, CER
Annonaceae	*Bocageopsis mattogrossensis*	AMR, CER, ATR
Polygalaceae	*Bredemeyera lucida*	AMR, CER
Combretaceae	*Buchenavia macrophylla*	AMR
Malpighiaceae	*Byrsonima arthropoda*	AMR, CER
Malpighiaceae	*Byrsonima chrysophylla*	AMR, CER, ATR
Salicaceae	*Casearia arborea*	AMR, CER, ATR
Peraceae	*Chaetocarpus echinocarpus*	AMR, CAA, CER
Connaraceae	*Connarus perrottetii*	AMR
Boraginaceae	*Cordia bicolor*	AMR, CAA, ATR
Euphorbiaceae	*Croton palanostigma*	AMR
Burseraceae	*Dacryodes microcarpa*	AMR
Ebenaceae	*Diospyros sericea*	CAA, CER
Sapotaceae	*Ecclinusa ramiflora*	AMR, ATR

Icacinaceae	*Emotum nitens*	AMR, CAA, CER, ATR
Fabaceae	*Enterolobium schomburgkii*	AMR, CER
Moraceae	*Ficus sp*	AMR, CAA, CER, ATR, PAN
Annonaceae	*Guatteria foliosa*	AMR
Annonaceae	*Guatteria scytophylla*	AMR
Bignoniceae	*Handroantus impetiginosus*	AMR, CAA, CER, ATR, PAN
Apocynaceae	*Himatanthus articulatus*	AMR, CER
Humiriaceae	*Humiria balsamifera*	AMR, CAA, CER, ATR
Fabaceae	*Hydrochorea corymbosa*	AMR, CER
Fabaceae	*Inga pezizifera*	AMR
Fabaceae	*Inga vera*	AMR, CER, ATR, PAN
Bignoniceae	*Jacaranda copaia*	AMR
Calophyllaceae	*Kielmeyera sp*	AMR, CAA, CER, ATR
Cunoniaceae	*Lamanonia ternata*	CER, ATR
Chrysobalanaceae	*Licania apetala*	AMR, CER, ATR
Chrysobalanaceae	*Licania kunthiana*	AMR, CAA, CER, ATR
Euphorbiaceae	*Mabea fistulifera*	AMR, CAA, CER, ATR
Fabaceae	*Machaerium myrianthum*	AMR
Melastomataceae	*Miconia brevipes*	AMR, CER
Melastomataceae	*Miconia egensis*	AMR
Melastomataceae	*Miconia cuspidata*	AMR, CER, ATR
Sapotaceae	*Micropholis guyanensis*	AMR, CER, ATR
Sapotaceae	*Micropholis venulosa*	AMR, CER, ATR
Olacaceae	*Minquartia guianensis*	AMR, CER
Myrtaceae	*Myrcia amazonica*	AMR, CER, ATR
Myrtaceae	*Myrcia splendens*	AMR, CAA, CER, ATR, PAN
Myrtaceae	*Myrciaria dubia*	AMR, CER
Myrtaceae	*Myrsine coriacea*	CER, ATR
Lauraceae	*Nectandra cuspidata*	AMR, CAA, CER
Lauraceae	*Nectandra hihua*	AMR, CER, ATR, PAN
Lauraceae	*Ocotea aciphylla*	AMR, CER, ATR
Lauraceae	*Ocotea leucoxylon*	AMR, ATR
Lauraceae	*Ocotea velloziana*	CAA, CER, ATR
Fabaceae	*Ormosia paraensis*	AMR
Lythraceae	*Physocalymma scaberrima*	-
Sapotaceae	*Pouteria filipes*	AMR, ATR
Sapotaceae	*Pouteria ramiflora*	AMR, CAA, CER, ATR
Burseraceae	*Protium heptaphyllum*	AMR, CAA, CER, ATR
Burseraceae	*Protium pilosissimum*	AMR, CER
Burseraceae	*Protium spruceanum*	AMR, CER, ATR
Moraceae	*Pseudolmedia laevigata*	AMR, CER, ATR
Moraceae	*Pseudolmedia laevis*	AMR
Vochysiaceae	*Qualea dichotoma*	CAA, CER, ATR
Quiinaceae	*Quiina cruegeriana*	AMR, CAA, ATR
Humiriaceae	*Sacoglottis guianensis*	AMR

Araliaceae	*Schefflera morototoni*	AMR, CAA, CER, ATR, PAN
Simaroubaceae	*Simarouba amara*	AMR, CAA, CER, ATR
Elaeocarpaceae	*Sloanea eichleri*	AMR, CER, ATR
Bigniceae	*Sparattosperma leucanthum*	AMR, CAA, CER, ATR, PAN
Fabaceae	*Tachigali vulgaris*	AMR, CER, ATR
Anacardiaceae	*Tapirira guianensis*	AMR, CAA, CER, ATR, PAN, PAM
Anacardiaceae	*Tapirira obtusa*	AMR, ATR, CER
Myristicaceae	*Virola calophylla*	AMR
Myristicaceae	*Virola sebifera*	AMR, CER, ATR
Hypericaceae	*Vismia macrophylla*	AMR, ATR
Annonaceae	*Xylopia amazonica*	AMR
Annonaceae	*Xylopia aromatica*	AMR, CER
Annonaceae	*Xylopia chivantinensis*	-
Annonaceae	*Xylopia polyantha*	AMR

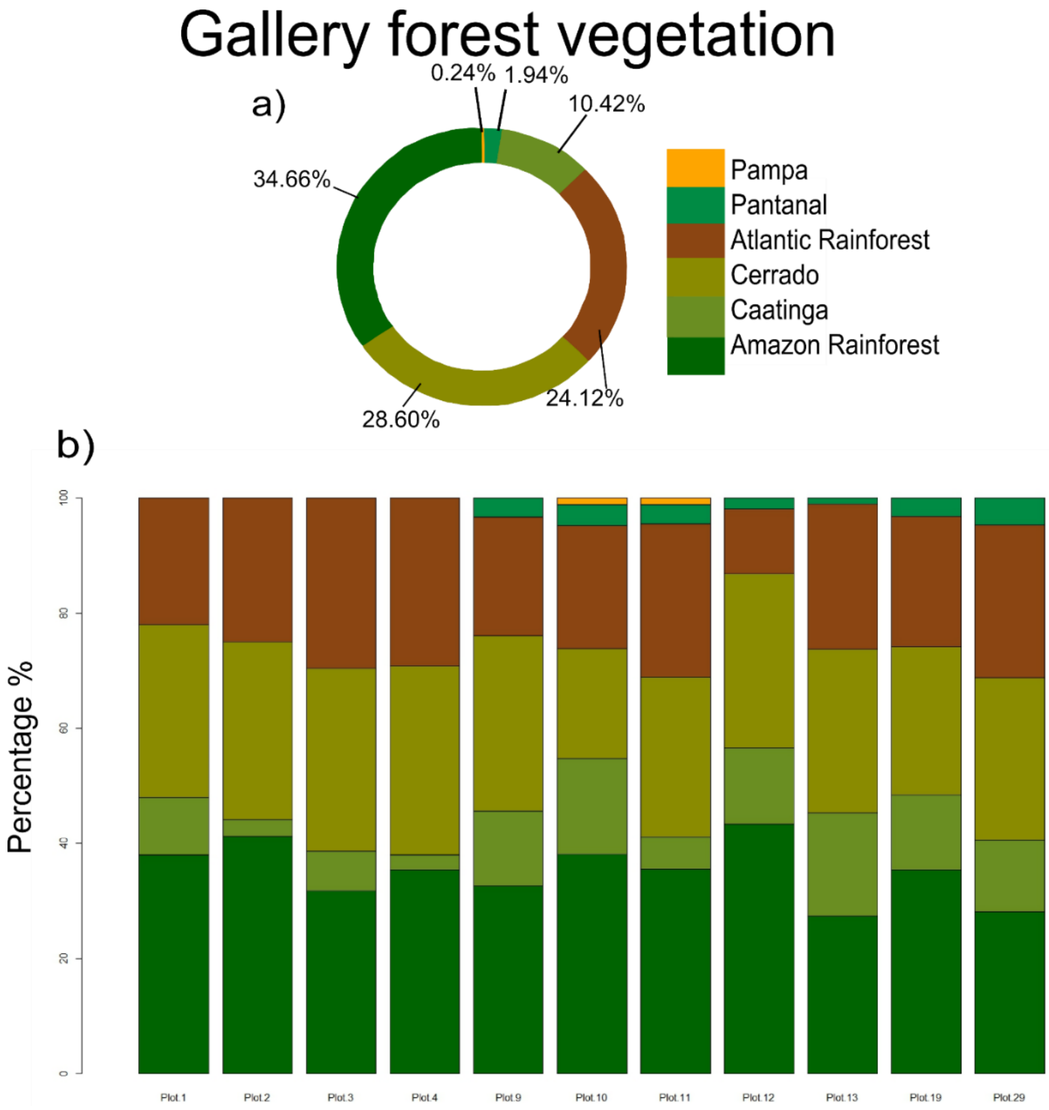

Figure 25. a) Percentage of the represented phytogeographic domains in gallery forest vegetation b) assemblage and phytogeographic distribution of the surveyed plant species in plots (1-4) and (9-13).

4.2 Assessment of a riparian zone as an ecosystem service provider in an agro-industrial area of the Cerrado [1]

To assess how the riparian zone in an intensively used agricultural zone in the Cerrado functions as an ecosystem service provider, we analyzed plant diversity and water quality indicators for the period of one month in a selected transect. In Transect 1 (see Fig. 14 in chapter 2), with *campo de murundus* and gallery forest formations, we analyzed water nutrient concentrations from baseflow and stormflow of the river discharge, overflow and groundwater from inside (gallery forest and *campo de murundus*) and outside sites (cropland area = PLU) of the riparian zone.

4.2.1 Riparian zone vegetation

The results of the vegetation survey of Transect 1 (Fig. 26) show that the floristic structure of the riparian zone was represented by a total of 28 different families. Each family is indicated only by numbers in the inner circle of the figure, these being: 1. *Anacardiaceae,* 2. *Annonaceae,* 3. *Apocynaceae,* 4. *Bignoniaceae,* 5. *Boraginaceae,* 6. *Burseraceae,* 7. *Ebenaceae,* 8. *Elaeocarpaceae, 9. Euphorbiaceae, 10. Fabaceae, 11. Humiriaceae, 12. Hypericaceae, 13. Icacinaceae, 14. Lauraceae, 15. Malpighiaceae; 16. Melastomataceae, 17. Moraceae, 18. Myristicaceae, 19. Myrtaceae, 20. Olacaceae, 21. Polygalaceae, 22. Primulaceae, 23. Rubiaceae, 24. Sapotaceae, 25. Simaroubaceae, 26. Siparunaceae, 27. Styracaceae,* and 28. *Symplocaceae.* The majority of species belonged to the *Melastomataceae*, *Anacardiaceae*, *Burseraceae*, *Euphorbiaceae* and *Simaroubaceae* botanical families (cf. Fig. 26 groups 16, 1, 6, 9 and 25 respectively). In our study area, where the riparian zone is located on a site surrounded by agricultural lands, the RZ provides the regional ecosystem with a total of 378 individuals from 66 different plant species.

The most abundant botanical families in the *campo de murundus* plots were the *Euphorbiaceae*, *Melastomataceae* and *Simaroubaceae* (Fig. 26, groups 9, 16 and 25, respectively). In this formation, a total of 15 botanical families were found, adding up to a total of 242 living individuals and 17 dead individuals belonging to 27 different plant species. In turn, the most abundant families in the gallery forest plots were the *Burseraceae* and

---

[1] Section resulting from paper – Nóbrega, R. L. B.; Ziembowicz, T. (et al.) (shared first-authorship). Assessment of a riparian zone as an ecosystem service provider in a agroindustrial area in the Amazonian Agricultural Frontier. Target Journal: Environmental Monitoring and Assessment.

Anacardiaceae. Throughout Transect 1 during the survey period, only one plant species could not be identified, and another specimen could only be assigned to its genus, *Symplocos*.

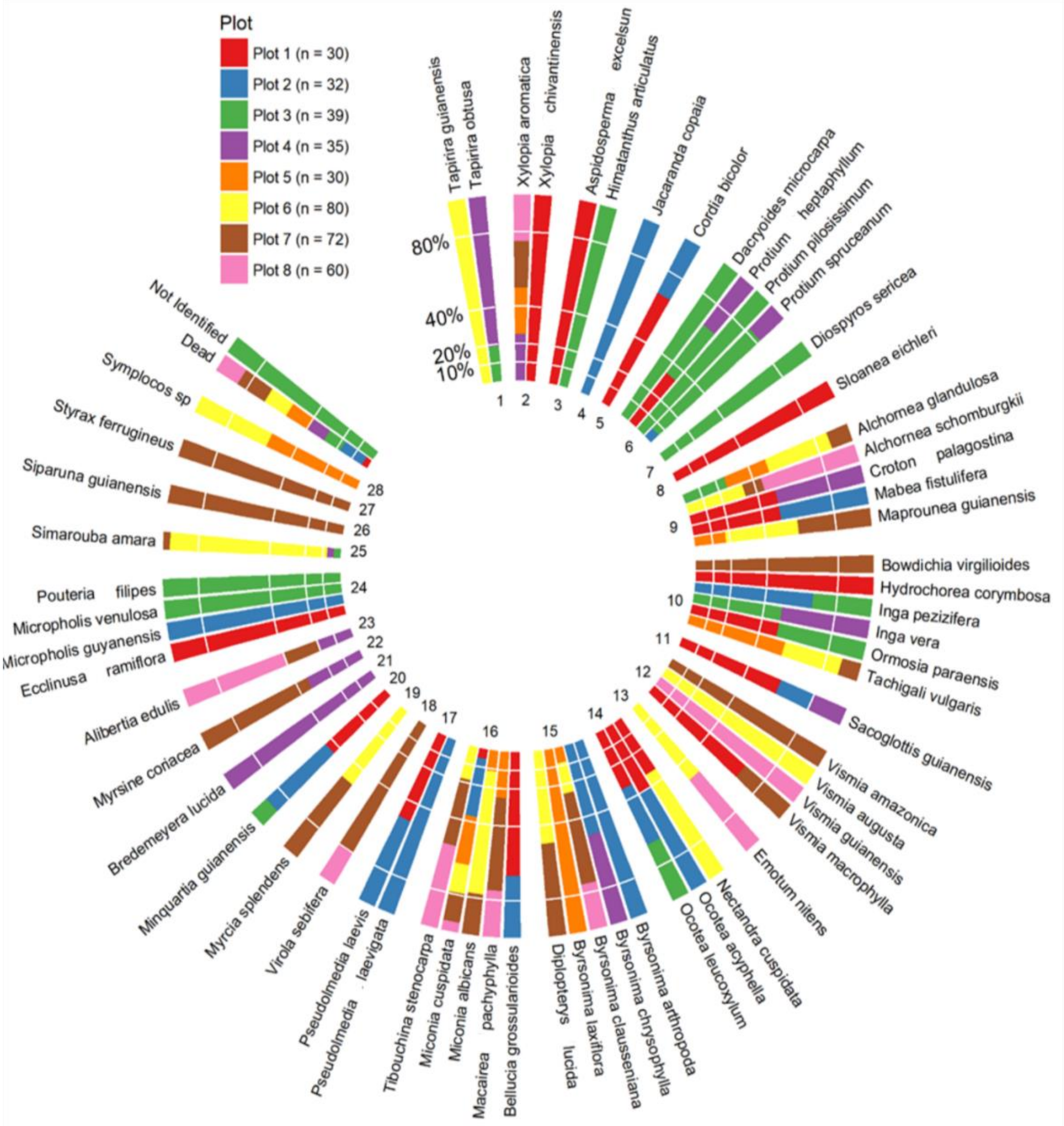

Figure 26. Number of plant species per family (n), and their proportional description by family in each plot of the transect. The numbers in the inner circle represent the botanical groups. Plots are color-coded according to the top-left legend.

Figure 27 shows a phytogeographic description of the plants surveyed. We aim here to illustrate the typical occurrence of each plant species within the Brazilian vegetation formations, i.e. in the Pantanal, Pampas, Cerrado, Caatinga, Atlantic rainforest and Amazon rainforest, as well as the typical gallery forest plants species (Jardim Botânico do Rio de Janeiro, n.d.; Oliveira-Filho and Ratter, 1995). The first four plots (1-4) of Transect 1 contained gallery forest, with the plant species in these plots predominantly belonging to the

Amazon rainforest, Atlantic rainforest and Cerrado vegetation types; there is no substantial difference in the proportions of these species between the plots. The last four plots (5-8) are located within the *campo de murundus*, where an increasing predominance of Cerrado-related vegetation and a decrease in Amazon-related vegetation exist. As the plots are located further from the gallery forest formation and closer to the predominant land use (PLU) area, typical Cerrado species begin to predominate. Figure 27b shows a summary of the two formations in the RZ of Transect 1, where the predominance of tropical wet forests over dry vegetation types in the gallery forest are evident, and the opposite relationship holds true in the *campo de murundus* area.

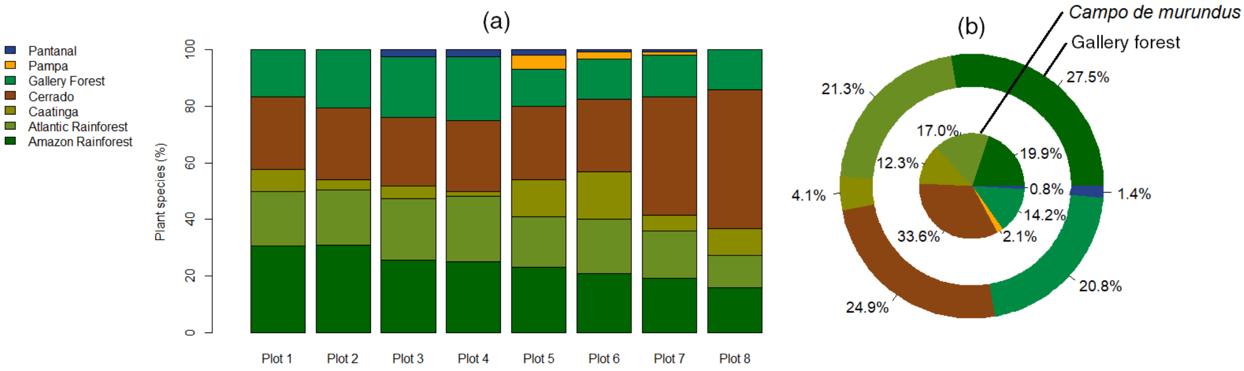

Figure 27. (a) Assembly and phytogeographic distribution of the surveyed plant species along the plots in Transect 1; (b) Percentage of the represented phytogeographic domains according to the two vegetation formations in Transect 1. Outer circle represents gallery forest (plots 1-4) and inner circle *campo de murundus* (plots 5-8).

In the study area, two types of vegetation which form a small mosaic with different types of plant species were present. Previous findings (Naiman et al., 1993) show that a mosaic of different types of vegetation and plant species in a riparian zone is a key element serving the ecosystem. It can enhance the ecological functions of the whole watershed, controlling light and temperature, offering shelter for biota, providing food for aquatic and terrestrial fauna, contributing with large and small woody debris that influence sediment directions, channelling morphology and microhabitats inside the river, controlling the flow of water and nutrients, and maintaining the local biodiversity (Naiman and Decamps, 1990; Weisberg et al., 2013). The vegetation in the present study area was perturbed by cattle and the activity of heavy machinery on the border between the cropland and *campo de murundus*. This can affect carbon pools, since the riparian vegetation and the soils below contribute to increasing biomass with carbon stocks over time (Rheinhardt et al., 2012).

4.2.2 Water quality

All the samples for the water quality analysis, were collected during a complete month in the 2013/2014 wet season. Stream water (river discharge) was measured continuously (10-min intervals) through a rectangular weir with v-notch contraction (also dry season). An automatic water sampler was installed at a depth of 20 cm to take samples of baseflow water and stormflow events (see Methods, Chapter 3). Baseflow and stormflow were separated using recursive digital filtering (Nóbrega et al., 2017). The overland flow samples were collected both inside and outside of the riparian zone plots after storm events, and with special flow detectors. The overland flow samplers were located on flowlines distributed over eight sites inside the RZ and ten sites in the cropland area outside the RZ. More on the water quality survey is described in detail in the Methods section, Chapter 3. Groundwater samples were taken every 15 days from eight wells located in the vegetation survey plots. The water samples described in this Results section covered all the hydrological pathways investigated, i.e. baseflow, stormflow, groundwater, riparian zone overflow (RZ) and predominant land use overflow (PLU).

To compare water quality between hydrological pathways, water nutrient concentrations were analyzed in the laboratory of UFMT and at the University Göttingen. The methods are described in Chapter 3. The water quality was analyzed separately according to hydrological pathway and grouped together by events (8 samples groundwater, 24 samples baseflow, 23 samples stormflow, 22 samples overflow RZ and 19 samples overflow PLU) and compared pair-wise using the non-parametric Mann-Whitney test.

The Mann-Whitney test values comparing the hydrological pathways are given in Table 8. The results showed that the baseflow samples had the lowest water nutrient concentration of all the water quality parameters, whereas the overflow water in the PLU (overflow PLU) area exhibited the higher concentrations in most of the cases (Figs. 28 and 29). Except for Na, the differences between the overflow PLU samples and the baseflow, overflow PLU and stormflow samples were all significant (*p* < 0.001). The overflow water in the RZ (overflow RZ) also exhibited higher concentrations than most of the other hydrological fluxes, but were still significant lower (*p* < 0.001) than the overflow PLU, with the exception of TOC, DOC and Na.

Table 8. Mann-Whitney test results for all nutrients analysed in all hydrological pathways.

TC	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**

Baseflow	$U = 2.5, p < 0.001$	$U = 0, p < 0.001$	$U = 0, p < 0.001$	$U = 0, p < 0.001$
Stormflow	-	$U = 40, p = 0.03$	$U = 12.5, p < 0.001$	$U = 23, p < 0.001$
Groundwater	-	-	$U = 17, p < 0.001$	$U = 26.5, p = 0.01$
Overflow RZ	-	-	-	$U = 260, p = 0.09$
TIC	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 2.72, p < 0.64$	$U = 0, p < 0.001$	$U = 80.5, p < 0.001$	$U = 2, p < 0.001$
Stormflow	-	$U = 0, p < 0.001$	$U=80, p < 0.001$	$U = 2.5, p < 0.001$
Groundwater	-	-	$U = 159.5, p < 0.001$	$U = 66.5, p = 0.78$
Overflow RZ	-	-	-	$U = 46, p < 0.001$
TOC	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 0, p < 0.001$	$U = 0.5, p < 0.001$	$U = 0, p < 0.001$	$U = 0, p < 0.001$
Stormflow	-	$U = 113, p = 0.16$	$U = 16, p < 0.001$	$U = 62, p < 0.001$
Groundwater	-	-	$U = 3, p < 0.001$	$U = 14, p < 0.001$
Overflow RZ	-	-	-	$U = 290.5, p = 0.01$
TN	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 39.5, p < 0.001$	$U = 16.5, p < 0.001$	$U = 0, p < 0.001$	$U = 0, p < 0.001$
Stormflow	-	$U = 124, p = 0.05$	$U = 7, p < 0.001$	$U = 34, p < 0.001$
Groundwater	-	-	$U = 0, p < 0.001$	$U = 3, p < 0.001$
Overflow RZ	-	-	-	$U = 171, p = 0.33$
DC	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 0, p < 0.001$	$U = 0.5, p < 0.001$	$U = 0, p < 0.001$	$U = 0, p < 0.001$
Stormflow	-	$U = 97, p = 0.84$	$U = 120.5, p < 0.001$	$U = 2, p < 0.001$
Groundwater	-	-	$U = 46.5, p = 0.05$	$U = 2, p < 0.001$
Overflow RZ	-	-	-	$U = 86.5, p = 0.001$
DIC	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 183, p = 0.16$	$U = 1.5, p < 0.001$	$U = 88.5, p = 0.003$	$U = 0, p < 0.001$
Stormflow	-	$U = 6.5, p < 0.001$	$U = 6.5, p < 0.001$	$U = 0, p = 0.001$
Groundwater	-	-	$U = 107.5, p = 0.002$	$U = 2, p = 0.05$
Overflow RZ	-	-	-	$U = 0, p = 0.007$
DOC	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 1.5, p < 0.001$	$U = 1.5, p < 0.001$	$U = 0, p < 0.001$	$U = 0, p < 0.001$
Stormflow	-	$U = 161, p = 0.002$	$U = 150.5, p = 0.02$	$U = 5, p < 0.001$
Groundwater	-	-	$U = 8.5, p < 0.001$	$U = 0, p < 0.001$
Overflow RZ	-	-	-	$U = 129.5, p = 0.04$
F	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 260.5, p = 0.69$	$U = 29.5, p = 0.001$	$U = 202, p = 0.11$	$U = 0, p < 0.001$
Stormflow	-	$U = 31.5, p = 0.002$	$U = 206.5, p = 0.23$	$U = 0, p < 0.001$
Groundwater	-	-	$U = 129, p = 0.04$	$U = 7.5, p < 0.001$
Overflow RZ	-	-	-	$U = 7.5, p < 0.001$
Cl	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 26, p < 0.001$	$U = 6.5, p < 0.001$	$U = 30, p < 0.001$	$U = 0, p < 0.001$
Stormflow		$U = 73.5, p = 0.41$	$U = 225, p = 0.53$	$U = 27.5, p < 0.001$
Groundwater			$U = 89.5, p = 0.96$	$U = 22.5, p = 0.005$
Overflow RZ				$U =116, p = 0.01$
SO$_4$	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 127.5, p = 0.004$	$U = 20, p = 0.001$	$U = 16, p < 0.001$	$U = 6, p < 0.001$
Stormflow	-	$U = 47, p = 0.04$	$U = 33, p < 0.001$	$U = 15.5, p < 0.001$
Groundwater	-	-	$U = 37.5, p = 0.02$	$U = 7, p < 0.001$
Overflow RZ	-	-	-	$U = 39, p < 0.001$
Al	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 66, p < 0.001$	$U = 96.5, p = 1$	$U = 0, p < 0.001$	$U = 2, p < 0.001$
Stormflow	-	$U = 155, p = 0.001$	$U = 37, p < 0.001$	$U = 61, p < 0.001$
Groundwater	-	-	$U = 0, p < 0.001$	$U = 0.5, p < 0.001$
Overflow RZ	-	-	-	$U = 263, p = 0.16$
Ca	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 178.5, p = 0.06$	$U = 0, p < 0.001$	$U = 77.5, p < 0.001$	$U = 0, p < 0.001$
Stormflow	-	$U = 1, p < 0.001$	$U = 95, p < 0.001$	$U = 1, p < 0.001$
Groundwater	-	-	$U = 148, p = 0.004$	$U = 59, p = 0.39$

Overflow RZ	-	-	-	$U = 50.5, p < 0.001$
K	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 2.5, p < 0.001$	$U = 2.5, p < 0.001$	$U = 0.5, p < 0.001$	$U = 3, p < 0.001$
Stormflow	-	$U = 145, p < 0.007$	$U = 258.5, p = 0.71$	$U = 22, p < 0.001$
Groundwater	-	-	$U = 49.5, p < 0.07$	$U = 8, p < 0.001$
Overflow RZ	-	-	-	$U = 39, p < 0.001$
Mg	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 203, p = 0.18$	$U = 64, p = 0.17$	$U = 133, p = 0.004$	$U = 5, p < 0.001$
Stormflow	-	$U = 74, p = 0.52$	$U = 152, p = 0.03$	$U = 0, p < 0.001$
Groundwater	-	-	$U = 66, p = 0.31$	$U = 0, p < 0.001$
Overflow RZ	-	-	-	$U = 25, p < 0.001$
Na	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 268.5, p = 0.93$	$U = 13, p < 0.001$	$U = 191.5, p = 0.11$	$U = 291.5, p = 0.12$
Stormflow	-	$U = 44.5, p = 0.04$	$U = 206.5, p = 0.41$	$U = 242.5, p = 0.39$
Groundwater	-	-	$U = 124, p = 0.10$	$U = 136, p = 0.001$
Overflow RZ	-	-	-	$U = 292.5, p = 0.03$
P	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 140.5, p = 0.006$	$U = 25.5, p = 0.002$	$U = 106.5, p < 0.001$	$U = 0, p < 0.001$
Stormflow	-	$U = 44.5, p = 0.04$	$U = 184, p = 0.17$	$U = 0, p < 0.001$
Groundwater	-	-	$U = 102.5, p = 0.51$	$U = 0, p < 0.001$
Overflow RZ	-	-	-	$U = 16, p < 0.001$
S	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 89, p < 0.001$	$U = 20, p < 0.001$	$U = 13, p < 0.001$	$U = 0, p < 0.001$
Stormflow	-	$U = 53, p = 0.10$	$U = 21, p < 0.001$	$U = 0, p < 0.001$
Groundwater	-	-	$U = 18.5, p = 0.001$	$U = 0, p < 0.001$
Overflow RZ	-	-	-	$U = 18.5, p < 0.001$
Si	**Stormflow**	**Groundwater**	**Overflow RZ**	**Overflow PLU**
Baseflow	$U = 179.5, p = 0.06$	$U = 8, p < 0.001$	$U = 117.5, p = 0.001$	$U = 41.5, p < 0.001$
Stormflow	-	$U = 7, p < 0.001$	$U = 183, p = 0.17$	$U = 119.5, p = 0.02$
Groundwater	-	-	$U = 170, p < 0.001$	$U = 148.5, p < 0.001$
Overflow RZ	-	-	-	$U = 184, p = 0.52$

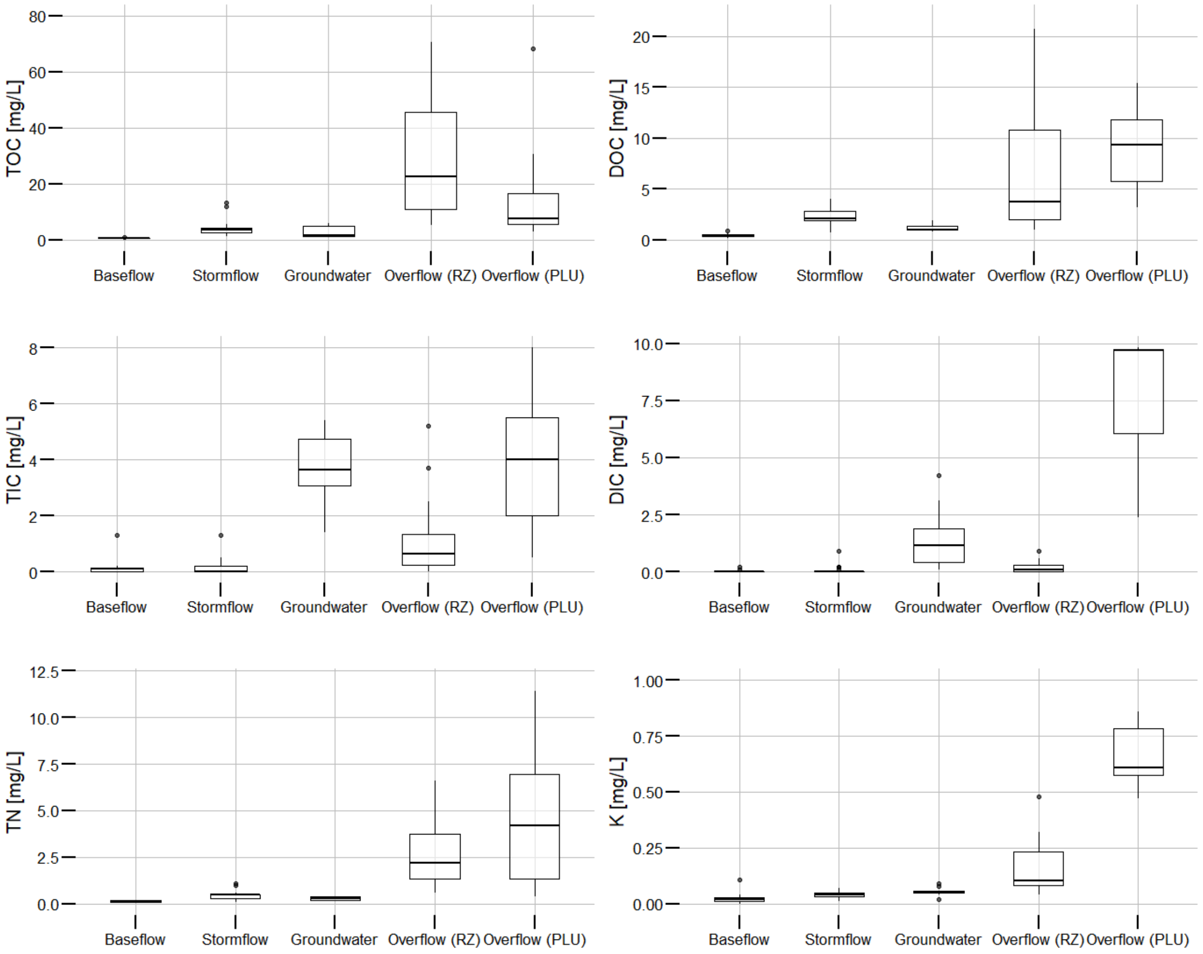

Figure 28. Water quality (TOC, DOC, TIC, DIC, TN and K) indicators in the analyzed area (Transect 1) for the different hydrological pathways. The overflow (PLU) samples are from outside the riparian zone.

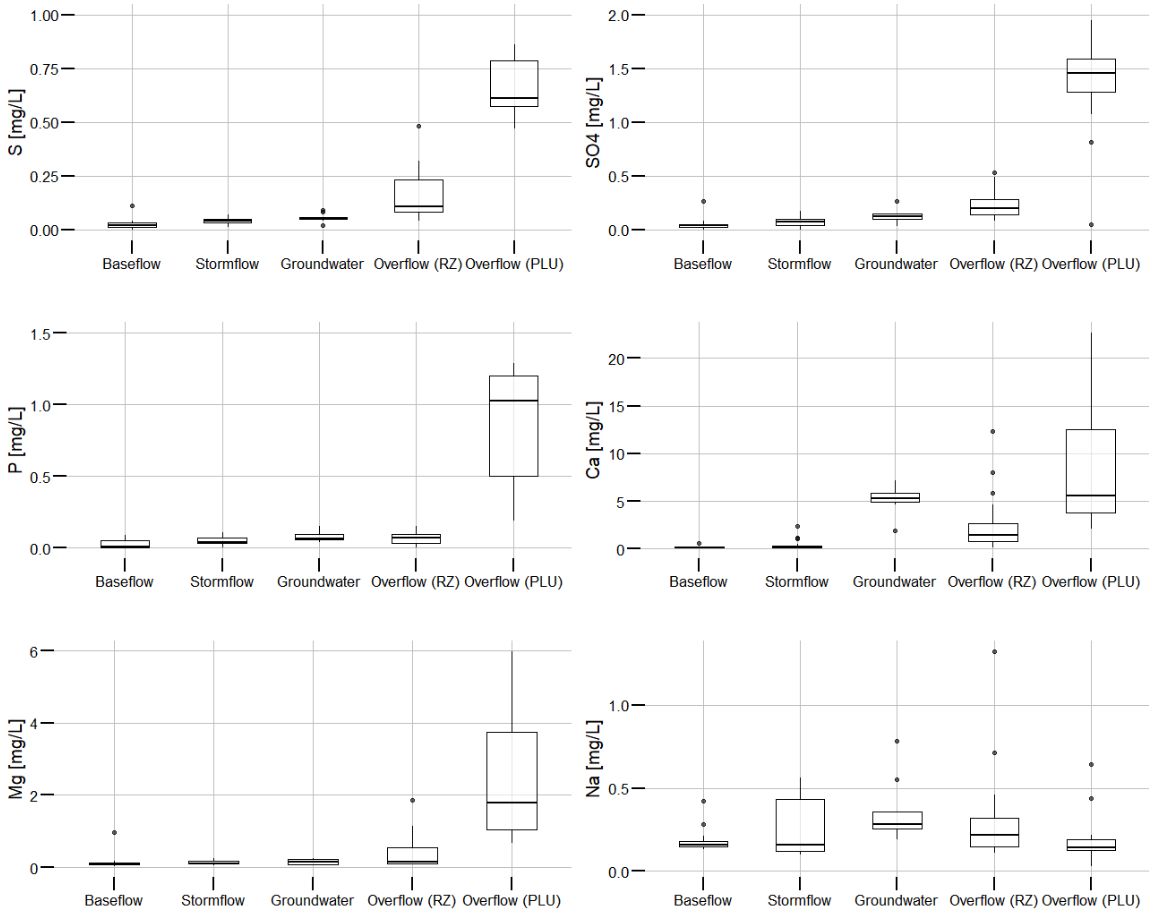

Figure 29. Water quality in different hydrological pathways (S, SO_4, P, Ca, Na and Mg) as measured throughout the study. The overflow (PLU) samples are from outside the riparian zone.

Overflow (PLU, RZ) and stream flow (baseflow, stormflow), showed significant differences with regard to TC, TIC, TOC, TN, DC, DIC, DOC, Cl, SO_4, Al, Mg, Ca, and S. However, there was no significant difference between stormflow and overflow RZ for Cl. No significant difference in F was found between baseflow and overflow RZ, or between stormflow and overflow RZ. The difference in K between stormflow and overflow RZ was not significant. We found no significant difference in Na between baseflow and overflow RZ, between stormflow and overflow RZ, between stormflow and overflow PLU. P did no show significant difference between stormflow and overflow RZ. Si did not show significant difference between stormflow and overflow RZ.

Groundwater and baseflow in the riparian zone showed significant differences with regard to TC, TIC, TOC, TN, DC, DIC, DOC, F, Cl, SO_4, Ca, K, Na, P, S and Si. Only two elements − Mg and Al − did not differ significantly here. Significant differences, influenced by higher overland flow (PLU) concentrations, were found between baseflow and stormflow for TC, TOC, TN, DC, DOC, SO_4, K, P and S. Significant differences were also found between baseflow and stormflow for Al and Cl, however these were not influenced by higher overland flow (PLU) concentrations.

4.3 Ecohydrological relations between woody plant diversity and groundwater in the Cerrado riparian zone

One of the aims of this thesis is to delineate possible relations between plant diversity, groundwater table depth and nutrient variations in Cerrado riparian zones highly impacted by agriculture. For this, 18 wells were placed in 18 plots within Transects 1 and 2, which contained gallery forest and *campo de murundus* vegetation. Besides our phytosociological survey in the targeted area, we measured groundwater depth and variations in nutrient content over a two-year period comprising both wet and dry seasons. We then statistically evaluated possible relations between the measured variables of interest with DCA analysis. The results are described in the section below.

4.3.1 Groundwater table depth

The absolute groundwater variations during the measurement period are shown in the boxplots for each well (Fig. 30 and 31). The minimum and maximum groundwater table depths ranged from 0.01 to 4.75 meters in the *campo de murundus* and from 0.35 to 5.83 meters in the gallery forest (Table 9). The depth-to-water levels in the wells in the *campo de murundus* locations (Wells 5, 6, 7, 8 and 16) were up to 10 cm below the soil surface for 57, 139, 60, 60 and 57 days respectively and up to 40 cm below the soil surface for 285, 293, 184, 130 and 32 days. Wells 17 and 18 were waterlogged up to 40 cm below the soil surface for 176 and 200 days. In addition, Wells 3 and 4, located very close to the stream in the gallery forest, were waterlogged up to 40 cm below the soil surface for a respective 41 and 113 days.

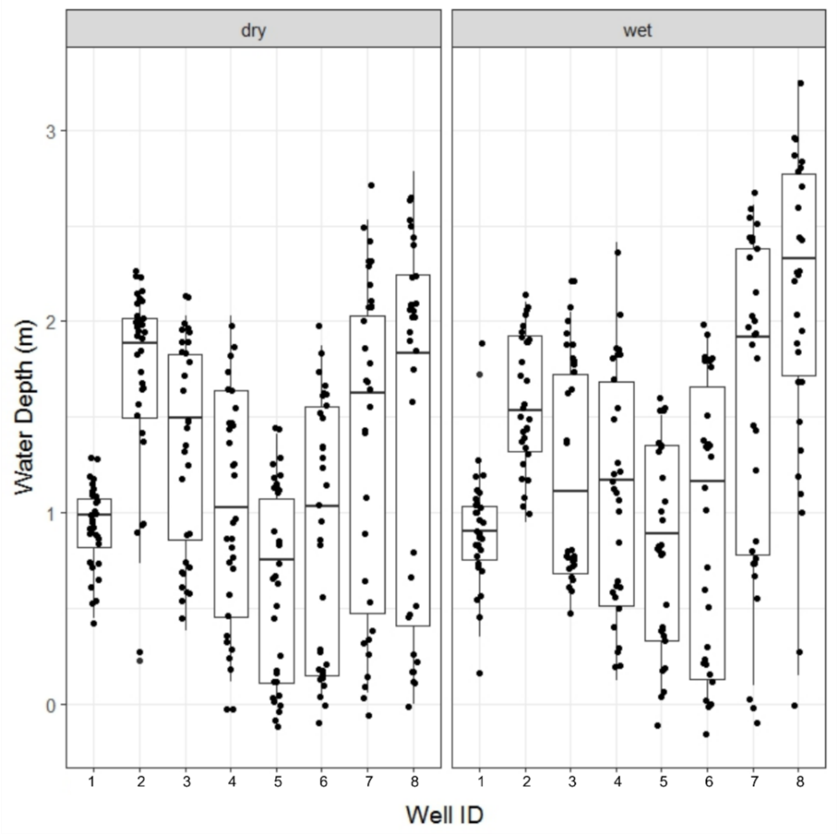

Figure 30. Groundwater fluctuations in the wet and dry seasons during 2014-2016 at Transect 1; Plot 1 is the one nearest to the river (see Fig. 14).

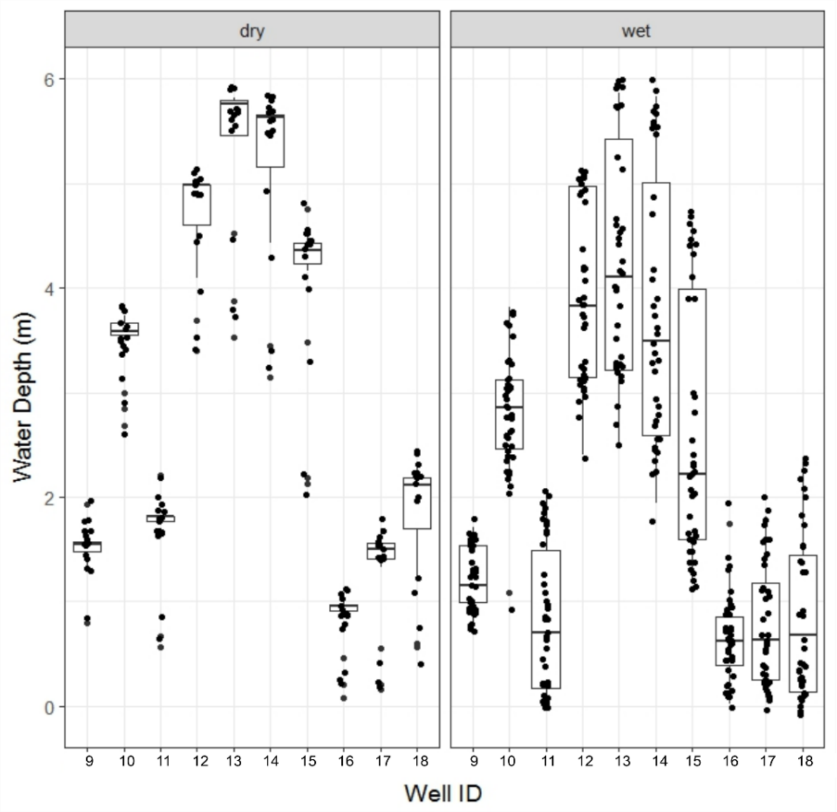

Figure 31. Groundwater fluctuations in the wet and dry season during 2014-2016 at Transect 2; Plot 9 is the nearest to the river (see Fig. 15).

Table 9. Summary of annual waterlogged days during the two years of measurements and well characteristics.

Vegetation type	Well number	Elevation (m)	Distance from river (m)	Water table at 10cm below surface (days)	Water table above 40 cm below surface (days)
Gallery forest	1	770.6	5	0	0
Gallery forest	2	772.3	20	0	0
Gallery forest	3	775.7	15	0	41
Gallery forest	4	773.8	10	0	113
Campo de murundus	5	768.5	67	57	285
Campo de murundus	6	769.4	113	139	293
Campo de murundus	7	770.7	165	60	184
Campo de murundus	8	771.6	214	60	130
Gallery forest	9	740.8	80	0	0
Gallery forest	10	741.2	130	0	0
Gallery forest	11	746.3	180	0	0
Gallery forest	12	746.0	230	0	0
Gallery forest	13	750.8	280	139	0
Campo de murundus	14	744.2	330	0	0
Campo de murundus	15	745.1	380	1	31
Campo de murundus	16	746.3	430	57	32
Campo de murundus	17	749.8	480	0	200
Campo de murundus	18	749.8	530	1	176

The minimum and maximum groundwater levels from the wells in Transect 1 during the wet season of 2014/2015 were between 0.12 and 2.05 meters below ground in the gallery forest, as compared to the *campo de murundus* plots, where they ranged from 0.1 to 2.94 meters below ground (Table 10). Moreover, the maximum and the minimum groundwater levels from the wells of Transect 2 during the wet season 2014/2015 were between 0.79 and 5.81 meters below ground in the gallery forest plots, compared to the *campo de murundus* plots with groundwater levels of 0.02 to 4.59 meters below ground (Table 10). In Transect 2, the groundwater table depth was lower in the gallery forest than in the *campo de murundus* formations. Also, in the *campo de murundus* the lowest maximum groundwater level was measured in Plot 14, located in a transition area between the two vegetation types. However, a different situation emerges if this plot is excluded, leaving us with values between 0.02 until 2.37 meters below ground in the *campo de murundus* (Table 10).

The minimum and maximum groundwater levels during the wet season of 2015/2016 in Transect 1 were between 0.23 and 1.92 meters below ground in the gallery forest as opposed to the *campo de murundus* where values ranged between 0.02 and 2.40 meters below ground (Table 10). The values in this transect confirm the waterlogged conditions of the *campo de murundus* formation, with its minimum value of 0.02 meters below ground, i.e. Wells 5, 6, and 8 remained waterlogged at 10 cm below surface for 57, 60 and 60 days respectively (Table 10). Transect 2, on the other hand, presented a minimum and maximum groundwater fluctuation during the 2015/2016 wet season of between 0.87 and 5.86 meters below ground in the gallery forest and a minimum and maximum groundwater fluctuation in the same season and transect for the *campo de murundus* of between 0.22 and 4.53 meters below ground − also indicating waterlogged conditions (Table 10). Well 16 in the *campo de murundus* was waterlogged at 10 cm below the surface for 57 days as was Well 13 in the gallery forest, also at 10 cm below the surface, for 139 days; but the latter well was near the road, which could be the reason for this condition (Table 9).

Table 10. Summary of annual groundwater table depths during the two years of measurements with average and standard deviation. Min = minimum, Max = maximum, SD = standard deviation.

Wells	**Average depth wet season (m)**	**Min wet season (m)**	**Max wet season (m)**	**SD**	**Average depth dry season (m)**	**Min dry season (m)**	**Max dry season (m)**	**SD**
1	0.85	0.35	1.17	0.23	0.90	0.66	1.17	0.14
2	1.64	0.23	2.10	0.48	1.58	0.74	2.12	0.43
3	1.38	0.38	2.05	0.60	1.05	0.56	1.53	0.32
4	1.09	0.12	1.89	0.65	0.75	0.15	1.34	0.37
5	0.81	0.02	1.51	0.55	0.36	0.01	0.92	0.33
6	1.06	0.02	1.93	0.72	0.50	0.03	1.14	0.44
7	1.64	0.06	2.61	0.92	0.86	0.10	1.76	0.62
8	1.83	0.02	2.94	1.09	0.94	0	2.01	0.75
9	1.25	0.80	1.71	0.29	1.38	0.80	1.93	0.27
10	2.95	1.08	3.82	0.60	3.21	2.68	3.63	0.34
11	4.22	2.98	5.01	0.77	4.26	3.40	4.93	0.53
12	4.69	2.89	5.86	1.06	4.65	3.53	5.75	0.72
13	4.30	2.31	5.83	1.25	4.30	3.14	5.13	0.68
14	3.00	1.21	4.59	1.21	3.60	2.13	4.37	0.80
15	1.05	0.02	2.05	0.67	1.21	0.57	2.21	0.62
16	0.48	0.02	1.27	0.37	0.59	0.04	1.07	0.38
17	0.88	0.08	1.80	0.55	0.99	0.16	1.63	0.51
18	1.35	0.43	2.37	0.65	0.93	0.57	1.31	0.39

The minimum and maximum groundwater fluctuations in the wells of Transect 1 during the dry season of 2015 ranged between 0.31 and 2.12 meters below ground in the gallery forest and between 0.01 and 1.83 meters in the *campo de murundus*. Furthermore, groundwater levels in Transect 2 during the dry season of 2015 ranged between a minimum of 0.8 and a maximum of 5.75 meters below ground in the gallery forest and between 0.16 and 4.16 meters below ground in the *campo de murundus*. In the dry season of the following year – 2016 − the groundwater in Transect 1's gallery forest wells fluctuated between a minimum and maximum of 0.15 and 1.94 meters below ground, compared to between 0 and 2.01 meters below ground in the *campo de murundus*. In this period of the year (beginning of the dry season), the groundwater remained near the soil surface in the *campo de murundus,* as the wet season 2015/2016 changed to dry season 2016. Similarly, Transect 2 showed minimum to maximum groundwater fluctuations in the wells from 1.14 to 5.12 meters below ground in the gallery forest, while it ranged in the *campo de murundus* from 0.04 to 4.36 meters below ground. The deepest ground-to-water level was measured in Well 14 (4.36 meters), but if this value is discounted, the average depth to water level was 1.63 meters below ground.

Measurements of groundwater levels showed waterlogging in Wells 5, 6, 7 and 8 of Transect 1 during the wet seasons of the two survey years, because the water levels reached the soil surface in these wells. In Wells 1, 2, 3 and 4, located in the gallery forest alongside the river in Transect 1, the groundwater level was very high, still never reached the soil surface. Similarly, Transect 2 was characterized by waterlogging in Wells 14, 15, 16, 17 and 18, since the groundwater levels also reached the soil surface during the wet season of 2015/2016, thus meaning that the *campo de murundus* was a flooded area during a part of the year. However, Wells 9, 10, 11, 12, and 13 in the gallery forest of the same transect had lower surface-to-groundwater levels, and only Wells 9 and 13 showed a higher groundwater level; Well 9 due to its proximity to the river and Well 13 because of proximity to the road.

4.3.2 Groundwater nutrient concentration

The nutrient concentrations in the groundwater were analyzed for 15 different cations and anions, as well as for different carbon and nitrogen parameters (see Tables 11, 12 and 13). The groundwater depth and groundwater nutrient distribution time-series were pooled plot-wise, and their variation compared within and between transects (independent samples) with the Kruskall-Wallis test. The Bonferroni correction for multiple comparisons was applied to the alpha level. When significant, the plots were paired and compared post-hoc with the Mann-Whitney test. The significance threshold was set at 0.05. In general, the nutrient concentration analysis revealed slight differences between the gallery forest and *campo de murundu*s, which will be described in the DCA analysis. The nutrient analysis showed no significant differences in concentration between wells in Transect 1 with regard to total organic carbon, sodium, iron, phosphorous, zinc, and ammonium. Also in Transect 2, no significant differences in concentrations of total organic carbon, total carbon, total nitrogen bound, sodium, zinc, phosphorous, manganese were found between wells.

Table 11. Nutrient concentrations in each plot. Values represent mean plus standard deviation.

Wells numbers	**F [mg/l]**	**Cl [mg/l]**	**NO_3 [mg/l]**	**SO_4 [mg/l]**	**NH_4 [mg/l]**	**Al [mg/l]**	**Ca [mg/l]**
1	0.03±0.01	0.34±0.18	0.67±0.44	0.07±0.03	0.05±0.04	0.02±0.03	1.27±1.31
2	0.03±0.01	0.51±0.39	1.82±3.45	0.05±0.05	0.12±0.18	0.01±0.02	1.06±0.99
3	0.03±0.01	0.71±0.30	1.32±1.07	0.09±0.08	0.04±0.03	0.005±0.006	3.19±1.99
4	0.03±0.01	0.54±0.45	1.69±1.55	0.06±0.04	0.13±0.28	0.03±0.11	3.70±1.93
5	0.03±0.01	0.40±0.61	1.38±3.08	0.05±0.02	0.07±0.11	0.01±0.03	2.17±1.65
6	0.03±0.01	0.42±0.45	1.18±2.89	0.06±0.04	0.13±0.18	0.01±005	2.46±2.09
7	0.03±0.01	0.29±0.23	0.77±1.50	0.05±0.05	0.09±0.22	0.005±0.008	2.92±2.44
8	0.04±0.03	0.34±0.25	0.92±1.64	0.05±0.03	0.07±0.09	0.004±0.003	3.61±2.20
9	0.02±0.02	0.50±0.52	3.03±6.51	0.05±0.11	0.09±0.09	0.03±0.06	1.60±1.63
10	0.02±0.01	0.35±0.29	0.97±1.73	0.09±0.08	0.18±0.16	0.009±0.004	0.85±0.74
11	0.03±0.02	0.35±0.34	0.37±0.21	0.12±0.01	0.14±0.09	0.01±0.004	1.09±0.81
12	0.02±0.01	0.18±0.17	0.50±0.46	0.08±0.13	0.48±0.68	0.008±0.005	0.79±0.71
13	0.02±0.01	0.15±0.11	0.27±0.16	0.03±0.02	0.12±0.09	0.008±0.004	0.69±0.57
14	0.03±0.01	1.23±0.73	1.84±3.42	0.17±0.09	0.11±0.07	0.009±0.007	1.62±0.98
15	0.02±0.01	0.71±0.37	0.74±1.59	0.19±0.08	0.21±0.14	0.01±0.01	1.35±0.93
16	0.02±0.01	0.23±0.27	1.07±2.93	0.23±0.55	0.16±0.12	0.03±0.07	0.39±0.70
17	0.02±0.02	0.28±0.35	0.26±0.27	0.12±0.17	0.16±0.14	0.01±0.02	1.42±2.10
18	0.02±0.02	0.42±0.27	1.27±2.36	0.05±0.02	0.04±0.04	0.01±0.01	2.85±1.66

Table 12. Nutrient concentrations in each plot. Values represent mean plus standard deviation.

WL	**Cu [mg/l]**	**Fe [mg/l]**	**K [mg/l]**	**Mg [mg/l]**	**Mn [mg/l]**	**Na [mg/l]**	**P [mg/l]**	**Zn [mg/l]**
1	0.039±0.04	0.003±0.002	0.29±0.10	0.10±0.12	0.006±0.002	0.49±0.22	0.009±0.006	0.13±0.10
2	0.027±0.02	0.002±0.001	0.35±0.28	0.12±0.05	0.006±0.006	0.57±0.31	0.009±0.005	0.10±0.07
3	0.013±0.006	0.002±0.003	0.45±0.12	0.22±0.08	0.003±0.003	0.63±0.31	0.009±0.005	0.07±0.04
4	0.018±0.04	0.001±0.005	0.48±0.23	0.17±0.08	0.002±0.002	0.56±0.29	0.009±0.004	0.09±0.07
5	0.013±0.01	0.001±0.003	0.30±0.12	0.13±0.06	0.002±0.0009	0.44±0.22	0.008±0.005	0.07±0.04
6	0.011±0.009	0.006±0.002	0.36±0.28	0.12±0.06	0.002±0.0009	0.51±0.40	0.008±0.004	0.05±0.03
7	0.010±0.006	0.001±0.001	0.29±0.14	0.11±0.08	0.001±0.0006	0.40±0.20	0.008±0.007	0.06±0.04
8	0.011±0.005	0.001±0.001	0.33±0.15	0.11±0.05	0.001±0.0007	0.46±0.22	0.008±0.004	0.07±0.05
9	0.060±0.01	0.005±0.001	0.47±0.40	0.21±0.39	0.009±0.036	0.44±0.29	0.004±0.003	0.17±0.14
10	0.065±0.03	0.001±0.002	0.30±0.17	0.09±0.08	0.005±0.012	0.41±0.23	0.006±0.008	0.18±0.14

11	0.108±0.08	0.001±0.03	0.28±0.21	0.06±0.03	0.006±0.006	0.41±0.31	0.003±0.002	0.24±0.14
12	0.025±0.01	0.001±0.001	0.20±0.16	0.06±0.03	0.006±0.022	0.31±0.20	0.009±0.021	0.09±0.06
13	0.023±0.01	0.001±0.001	0.21±0.19	0.06±0.08	0.005±0.187	0.26±0.12	0.005±0.007	0.08±0.05
14	0.023±0.02	0.001±0.01	0.38±0.16	0.17±0.12	0.010±0.027	0.50±0.22	0.004±0.002	0.13±0.07
15	0.013±0.01	0.002±0.001	0.21±0.25	0.13±0.26	0.005±0.014	0.39±0.28	0.003±0.002	0.07±0.08
16	0.019±0.04	0.009±0.001	0.18±0.24	0.09±0.20	0.003±0.013	0.38±0.28	0.004±0.003	0.07±0.11
17	0.028±0.04	0.001±0.0009	0.27±0.13	0.17±0.11	0.008±0.156	0.56±0.27	0.007±0.004	0.12±0.14
18	0.022±0.01	0.001±0.002	0.46±0.22	0.56±0.21	0.050±0.009	0.64±0.27	0.006±0.003	0.09±0.04

Table 13. Total carbon and dissolved carbon parameters in each well. Values represent mean plus standard deviation.

WL	**TC [mg/l]**	**TIC [mg/l]**	**TOC [mg/l]**	**TNb [mg/l]**	**DC [mg/l]**	**DIC [mg/l]**	**DOC [mg/l]**	**DNb [mg/l]**
1	3.51 ±3.28	0.71±1.07	2.92±3.21	0.56±0.57	1.80±0.82	0.70±0.16	1.1±0.29	0.4±0.73
2	2.55±2.03	0.52±0.82	2.14±1.91	0.76±0.89	1.58±0.99	0.46±0.51	1.1±0.62	0.7±0.91
3	4.27±3.44	2.21±3.42	2.92±3.19	0.62±0.36	2.74±1.33	1.62±0.39	1.1±0.44	0.5±0.32
4	4.04±3.04	1.79±0.82	2.44±2.97	0.75±0.52	2.88±0.85	1.65±0.56	1.2±0.53	1.2±2.97
5	2.67±2.25	0.91±0.69	1.86±2.16	0.70±0.97	1.87±0.73	0.93±0.35	0.9±0.48	0.8±1.23
6	4.50±4.94	1.12±1.07	3.61±4.94	0.74±0.89	2.12±1.16	1.05±0.59	1.1±0.59	1.2±3.11
7	3.771±4.59	1.29±1.42	2.68±4.39	0.51±0.51	2.33±1.74	1.40±0.25	0.9±0.82	0.5±0.85
8	3.79±2.10	1.94±1.28	2.13±1.45	0.52±0.42	2.84±1.48	1.87±0.50	1.0±0.54	0.5±0.49
9	3.89±2.08	0.51±0.45	3.38±2.05	0.87±1.39	2.00±1.07	0.67±0.56	1.36±0.80	1.00±2.02
10	3.93±4.87	0.37±0.38	3.56±4.83	0.65±0.55	1.44±0.75	0.53±0.46	0.91±0.37	0.43±0.50
11	5.39±5.19	0.74±0.49	4.65±4.97	0.55±0.32	1.61±0.84	0.71±0.49	0.91±0.46	0.25±0.12
12	4.06±4.32	0.43±0.61	3.63±4.02	0.73±1.18	1.37±1.27	0.6±0.68	0.8±0.62	0.4±0.69
13	4.09±7.39	0.48±0.51	3.58±6.99	0.42±0.43	1.13±0.70	0.48±0.44	0.65±0.35	0.19±0.10
14	4.69±4.42	1.38±0.53	3.32±4.16	0.66±0.92	2.7±1.06	1.62±0.44	1.08±0.67	0.48±0.72
15	4.19±6.21	0.82±1.79	3.37±4.57	0.45±0.61	1.79±2.19	0.89±1.68	0.9±0.64	0.28±0.31
16	70.41±165.17	1.88±3.40	68.51±161.93	5.27±11.31	1.09±0.96	0.21±0.40	0.89±0.81	0.49±1.13
17	16.32±39.16	1.6±2.60	15.34±37.26	1.24±2.09	1.93±1.16	0.83±0.56	1.08±0.70	0.46±0.42
18	4.19±3.44	0.95±0.45	3.25±3.36	0.62±0.60	2.27±0.70	1.08±0.39	1.2±0.67	0.66±1.18

The results of our analysis of the carbon and nitrogen in the two transects is shown in Table 3.5. We found higher TC values for the *campo de murundus* plots in Transect 2, however the differences were not significant ($\chi^2(9) = 11.06$, $p = 0.27$). Similar values were found for both vegetation types in Transect 1, but in this case the differences reached significance ($\chi^2(7) = 15.69$, $p = 0.03$). There were high values for TIC in both transects, with these significantly different between gallery forest and *campo de murundus* plots ($\chi^2(9) = 51.11$, $p < 0.01$ Transect 2, and $\chi^2(7) = 60.48$, $p < 0.01$ Transect 1). Also, the TIC values in the *campo de murundus* were significantly higher than the gallery forest in both transects ($\chi^2(17) = 126.87$, $p < 0.01$). There was significant differences in TNb between the gallery forest and *campo de murundus* plots in Transect 1 ($\chi^2(7) = 19.14$, $p < 0.01$), but no significant differences between plots in Transect 2 ($\chi^2(9) = 12.98$, $p = 0.16$).

We found significant differences between all plots in Transect 1 with regard to DC ($\chi^2(7) = 38.79$, $p < 0.01$), but in Transect 2 differences were only significant between the gallery forest and *campo de murundus* plots ($\chi^2(9) = 47.94$, $p < 0.01$). The DIC analysis, on the other hand, showed significant differences between gallery forest and *campo de murundus* plots in both Transect 1 ($\chi^2(7) = 69.985$, $p < 0.01$) and Transect 2 ($\chi^2(9) = 70.11$, $p < 0.01$). Differences in DNb were also significant between plots in Transect 1 ($\chi^2(7) = 14.30$, $p = 0.05$), as well as in Transect 2 ($\chi^2(9) = 17.09$, $p = 0.05$). In addition, differences in DOC were significant between wells in the Transect 1 ($\chi^2(7) = 15.55$, $p = 0.03$) and the same was true for Transect 2 ($\chi^2(9) = 21.93$, $p < 0.01$).

In addition to the carbon and nitrogen concentrations, we also analyzed 15 cations present in the groundwater of the 18 wells. The Ca concentration (Fig. 32, and 33) showed significant differences in both transects between gallery forest and *campo de murundus* plots (Transect 1, $\chi^2(10) = 75.77$, $p < 0.01$; Transect 2, $\chi^2(9) = 75.29$, $p < 0.01$). There were no significant differences in Fe between gallery forest and *campo de murundus* plots in Transect 1, but these did occur in Transect 2 ($\chi^2(12) = 23.74$, $p = 0.02$). For Cu we found significant differences between plots in Transect 1 ($\chi^2(7) = 44.57$, $p < 0.01$) and also in Transect 2 ($\chi^2(9) = 60.87$, $p < 0.01$). Specifically, Cu was higher in the gallery forest plots, with significant differences in concentration than in *campo de murundus* plots; this held true in both transects ($\chi^2(17) = 133.6$, $p < 0.01$). The K concentration was significantly different between gallery forest and *campo de murundus* plots in both transects (Transect 1, $\chi^2(7) = 43.72$, $p < 0.01$; Transect 2, $\chi^2(9) = 48.62$, $p < 0.01$).

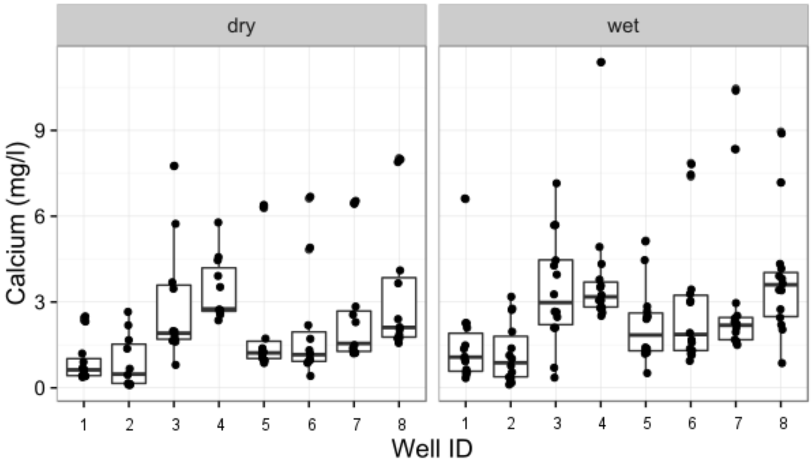

Figure 32. Calcium content in each plot of Transect 1 during the two years of the survey, separated by dry and wet season.

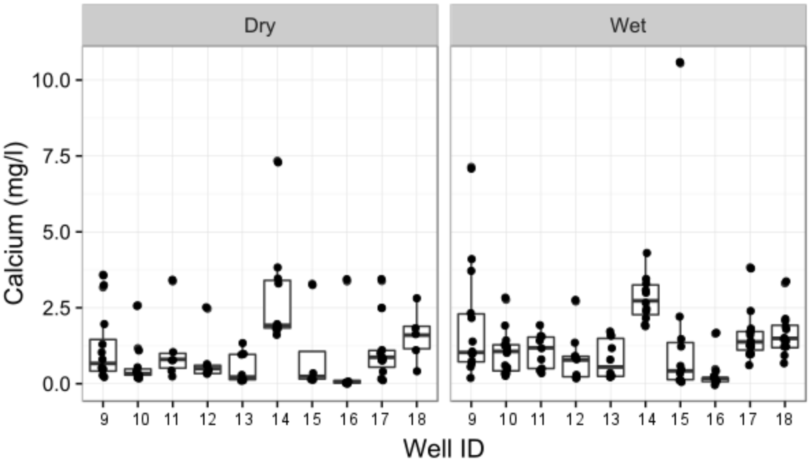

Figure 33. Calcium content in each plot of the Transect 2 during the two years of the survey, separated by dry and wet season.

The Mg concentrations in both transects are significantly different between the gallery forest and *campo de murundus* plots (Transect 1, $\chi^2(7) = 68.40$, $p < 0.01$; Transect 2, $\chi^2(9) = 88.77$, $p < 0.01$). Mn differed significantly only between the plots in Transect 1 ($\chi^2(7) = 18.40$, $p = 0.01$). In Transect 1, chloride values were higher for the gallery forest than for the *campo de murundus,* whereas the reverse was true in Transect 2. In both transects, the Cl concentration was significantly different between gallery forest and *campo de mruundus* plots (Transect 1, $\chi^2(7) = 45.42$, $p < 0.01$; Transect 2 $\chi^2(7) = 87.71$, $p < 0.01$), with the Cl values not surpassing 3 mg/l (Fig. 34 and 35). There were only significant differences in NH_4 in the Transect 2 ($\chi^2(9) = 23.41$, $p < 0.01$). In turn, nitrate in Transect 2 differed between the wet and dry seasons, and there were slight differences between gallery forest and *campo de murundus* (Fig. 36 and 37). Nitrate in the Transect 1 showed similar values between both seasons and slight differences between wells. There were significant differences in NO_3 in both transects (Transect 1, $\chi^2(7) = 56.11$, $p < 0.01$; Transect 2, $\chi^2(9) = 57.72$, $p < 0.01$). Sulphate was higher in the gallery forest than the *campo de murundus* in both transects, except for Well 18 (Fig. 38 and 39). We found significant differences regarding SO_4 between the gallery forest and *campo de murundus* plots in both transects (Transect 1, $\chi^2(7) = 21.29$, $p < 0.01$; Transect 2, $\chi^2(9) = 51.60$, $p < 0.01$). For Al the differences were significant only between the gallery forest and *Campo de murundus* plots in both transects (Transect 1, $\chi^2(7) = 22.07$, $p = 0.002$; Transect 2, $\chi^2(9) = 18.24$, $p = 0.03$).

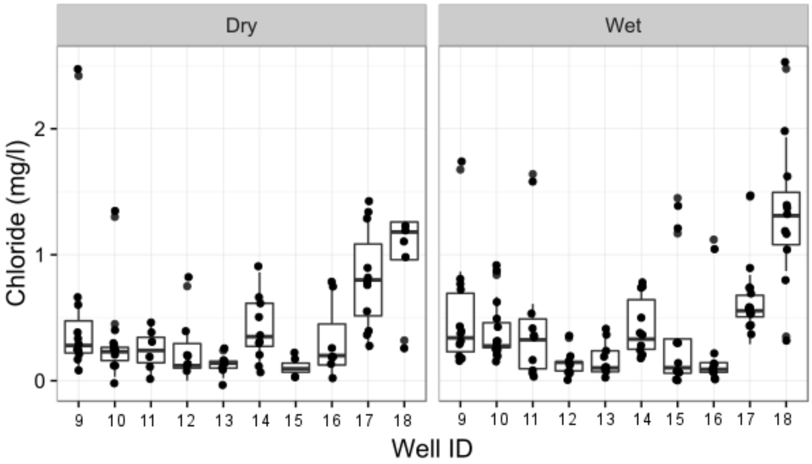

Figure 34. Chloride content in each plot of Transect 2 during the two years of the survey, separated by dry and wet season.

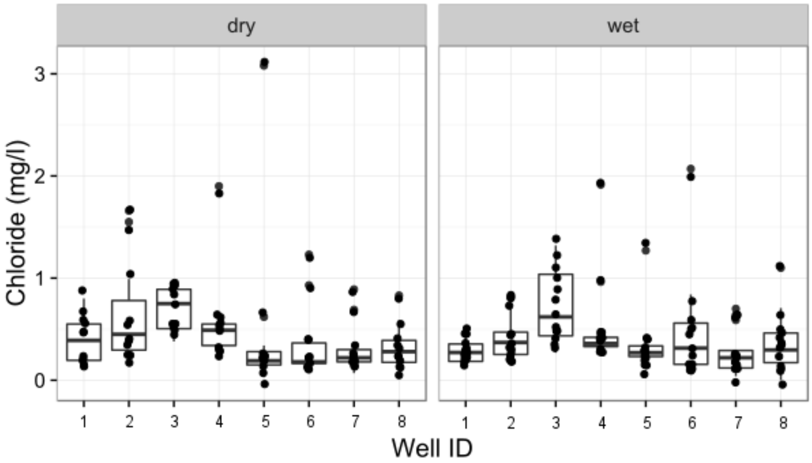

Figure 35. Chloride content in each plot of Transect 1during the two years of the survey, separated by dry and wet season.

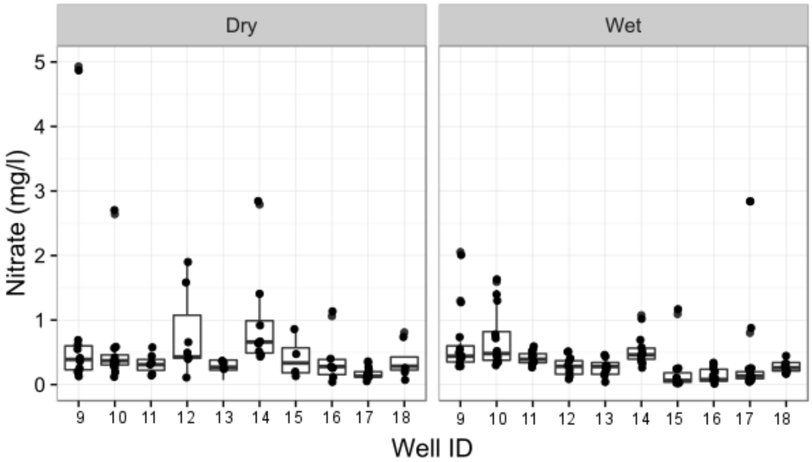

Figure 36. Nitrate content in each plot of the Transect 2 during the two years of the survey, separated by dry and wet season.

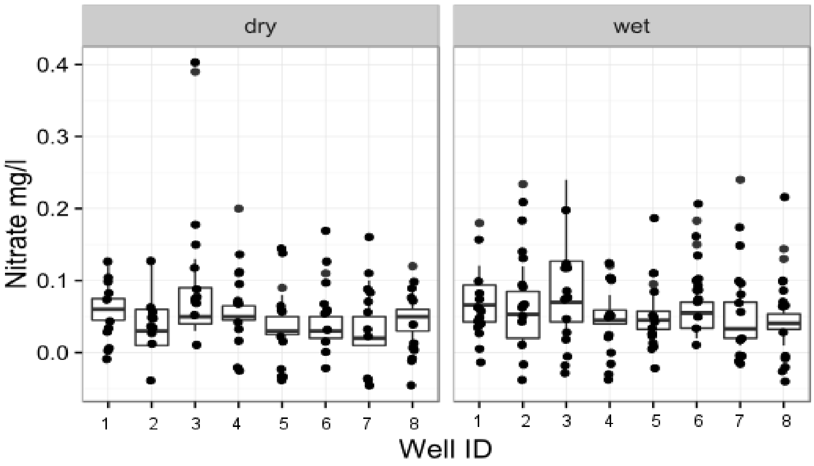

Figure 37. Nitrate content in each plot of Transect 1 during the two years of the survey, separated by dry and wet season.

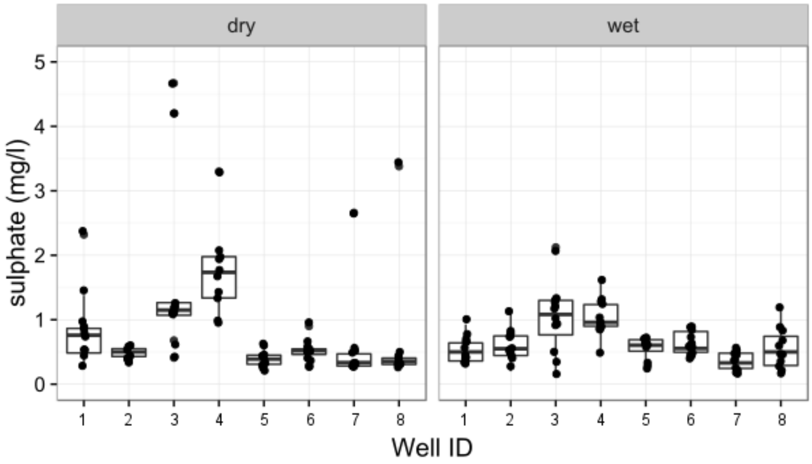

Figure 38. Sulphate content in each plot of Transect 1 during the two years of the survey, separated by dry and wet season.

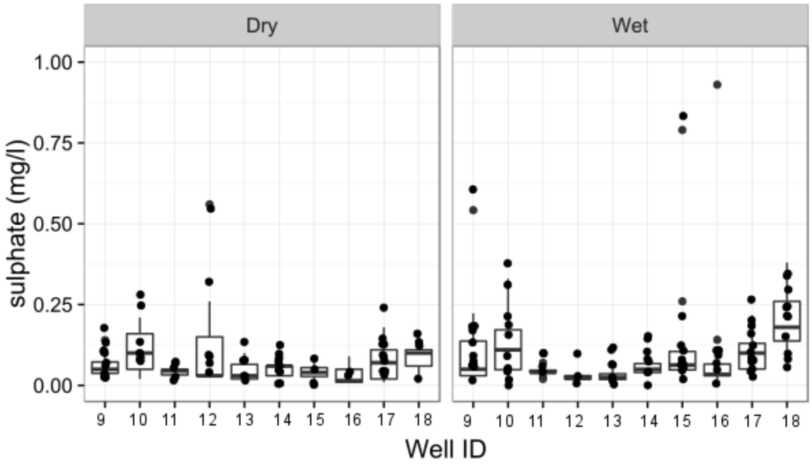

Figure 39. Sulphate content in each plot of Transect 2 during the two years of the survey, separated by dry and wet season.

Remarkably, the calcium analysis gave values ranging from 0.01 up to 10.55 mg/l for Transect 2 (Fig. 33) and from 0.11 to 11.38 for Transect 1. Our data showed higher values than the wells in the municipality of Campo Verde monitored by the Brazilian National Water Agency (ANA), which varied from 0 to 2.13 mg/l (ANA, 2017). However, the mean values from both transects ranged from 0.39 to 3.61, showing a similar pattern to the ANA wells. In addition, the iron concentrations were very low in the study area compared to the wells from ANA in Campo Verde. In Transect 1, our iron values ranged from 0 to 0.105 mg/l and from 0.001 to 0.009 mg/l in Transect 2, whereas they varied from 0 to 0.69 mg/l within the municipality.

4.3.3 Vegetation and biodiversity indexes

In the plant diversity survey covering the two transects, we identified a total of 320 tree species in the gallery forest plots and 614 tree species in the *campo de murundus* plots. The most common plant species in the gallery forest were: *Amaioua guianensis, Cordia bicolor, Inga vera, Minquartia guianensis, Protium spruceanum, Tapirira obtusa.* In turn, the most common species in the *campo de murundus* were*: Byrsonima clausseniana*, *Maprounea guianensis, Miconia albicans, Miconia cuspidata, Tachigali vulgaris, Tibouchina stenocarpa* and *Xylopia aromatica* (Table 14 and 15).

For the analysis proposed in this chapter, we used two of the measured indexes to estimate plant diversity, namely the Shannon and the Simpson indexes. Surprisingly, Shannon’s index (H’index) showed relatively normal values in both transects, varying between 1.5 and 3 (MacDonald, 2003), which indicates a normal diversity of plants despite the area being highly impacted by agroindustrial activity. The α-biodiversity (H index) revealed an average in both transects of 2.67 in the gallery forest and of 2.57 in the *campo de murundus,* with a variance of 1.6 to 2.8. Nevertheless, these values are lower than previous findings, where a surveyed gallery forest in the Cerrado environment had an H’ index ranging between 3.57 and 4.21, indicating a very high plant diversity (Marimon et al., 2002). Interestingly, in our intensively impacted transects, the *campo de murundus* gave us H’ values similar to those of De Oliveira-Filho (1992), who investigated this formation surrounded by intact Cerrado countryside. Plot 4 (high groundwater level) and 8 (deeper groundwater level) both presented H’ values lower than 2 which, though indicating a relatively normal amount of diversity, is still less than the other plots. Meanwhile, Plot 17, located inside a *campo de murundus* patch and characterized by a high groundwater level in the wet season, showed the highest H’ value for both transects. However, previous findings in the Cerrado showed a decrease in diversity when the groundwater was high (i.e. reached the soil level) (Villalobos-Vega et al., 2014b). As to the Simpson index, our results did not show differences between the two transects, though the D index in the first transect was higher in Plots 4 and 8 (Fig. 40 and 41).

Table 14. A complete list of plant species from the c*ampo de murundus* areas. The sp. indicates that only the genus was identified. The plants used as bioindicators in the DCA analysis are specified in bold.

Botanical Family	**Species**	**N**	**Plot/well**
Anacardiaceae	*Tapirira guianensis*	2	6
Anacardiaceae	*Tapirira obtusa*	8	16,17
Annonaceae	*Bocageopsis mattogrossensis*	2	17
Annonaceae	*Guatteria schytophyla*	2	7
Annonaceae	*Onychopetalum amazonicum*	4	15,16,17
Annonaceae	***Xylopia aromatica***	41	5,7,8,14,15,16,17,18
Apocynaceae	*Aspidosperma macrocarpum*	1	17
Aquifoliaceae	*Ilex sp.*	1	16
Calophyllaceae	*Kielmeyera coriacea*	3	15,17,18
Chrysobalanaceae	*Hyrthella glandulosa*	1	17
Connaraceae	*Connarus perrotettii*	1	17
Connaraceae	*Connarus suberosus*	5	15,16,17
Dilleniaceae	*Davilla elliptica*	2	18
Erythroxylaceae	*Erythroxilum egleri*	5	17
Euphorbiaceae	*Alchornea glandulosa*	5	5,6,7
Euphorbiaceae	*Alchornea schomburgkii*	9	6,7,8
Euphorbiaceae	***Maprounea guianensis***	46	5,6,7,14,15,16,17,18
Fabaceae	*Bowdichia virgilioides*	1	7
Fabaceae	***Tachigali vulgaris***	27	5,6,7,14,15,17,18
Hypericaceae	*Vismia amazonica*	1	7
Hypericaceae	*Vismia augusta*	2	6
Hypericaceae	***Vismia guianensis***	17	8,14,15,16,17,18
Hypericaceae	*Vismia macrophylla*	1	7
Icacinaceae	*Emotum nitens*	11	6,8,17,18
Lacistemataceae	*Lacistema aggregatum*	1	17
Lauraceae	*Nectandra cuspidata*	6	6,15,16,18
Lauraceae	*Ocotea velloziana*	3	15,17
Lythraceae	*Physocalymna scaberrima*	1	18
Malpighiaceae	*Banisteriopsis sp.*	2	17,18
Malpighiaceae	*Byrsonima clausseniana*	33	5,6,7,8,14,15,16,17,18
Malpighiaceae	*Byrsonima laxiflora*	4	5,14

Malpighiaceae	*Byrsonima pachyphylla*	10	16,17
Malpighiaceae	*Diplopterys lucida*	2	6,7
Malpighiaceae	*Heteropterys byrsonimifolia*	8	15,16,17
Malpighiaceae	*Heteropterys mircini*	1	16
Malvaceae	*Eriotheca gracilipes*	5	14,17
Melastomataceae	*Macairea pachyphylla*	4	5,7,8
Melastomataceae	***Miconia albicans***	21	6,7,8,14,15,16,17,18
Melastomataceae	*Miconia cuspidata*	15	5,6,7,8,16,17
Melastomataceae	*Miconia ferruginata*	1	17
Melastomataceae	***Tibouchina stenocarpa***	161	6,7,8,14,15,17,18
Myristicaceae	*Virola sebifera*	5	7,8
Myrtaceae	*Eugenia chrysantha*	2	17
Myrtaceae	*Myrcia guianensis*	2	17,18
Myrtaceae	*Myrcia splendens*	7	6,7,17,15
Myrtaceae	-	8	16,17
Myrtaceae	*Psidium sp.*	5	15,17,18
Ochnaceae	*Ouratea hexasperma*	9	15,17
Primulaceae	*Cybianthus detergens*	3	17
Primulaceae	*Myrsine coriacea*	2	7
Primulaceae	*Rapanea guianensis*	9	15,17
Proteaceae	*Roupala montana*	1	18
Rubiaceae	*Alibertia edulis*	6	7,8,15,18
Salicaceae	*Casearia arborea*	8	15,16,17,18
Simaroubaceae	*Simarouba amara*	34	6,7,16,17
Siparunaceae	*Siparuna guianensis*	3	7,17
Styracaceae	*Styrax ferrugineus*	3	7,15
Symplocaceae	*Symplocos sp.*	9	5,6
Vernonieae	*Pyptocarpha rotundifolia*	11	15,16,17
Vochysiaceae	*Qualea dicothoma*	5	16,17
Vochysiaceae	*Qualea grandiflora*	4	18
Vochysiaceae	*Qualea parviflora*	1	18

Table 15. A complete list of plant species from the gallery forest areas. The sp. indicates that only the genus was identified. The plants used as bioindicators in the DCA analysis are specified in bold.

Botanical families	**Species**	**N**	**Plots/wells**
Anacardiaceae	*Tapirira guianensis*	2	10,11
Anacardiaceae	*Tapirira obtusa*	27	3,4,13
Annonaceae	*Bocageopsis mattogrossensis*	1	12
Annonaceae	*Guatteria foliosa*	2	11,13
Annonaceae	*Guatteria schytophyla*	2	3,10
Annonaceae	*Xylopia amazonica*	6	12
Annonaceae	*Xylopia aromatica*	1	4
Annonaceae	*Xylopia chivantinensis*	1	1
Annonaceae	*Xylopia polyantha*	4	10
Apocynaceae	*Aspidosperma excelsum*	1	1

Apocynaceae	*Aspidosperma desmanthum*	1	13
Apocynaceae	*Himatanthus articulatus*	1	3
Araliaceae	*Schefflera morototoni*	3	9,10
Bignoniceae	*Handroantus impetiginosus*	1	13
Bignoniceae	*Jacaranda copaia*	3	2,9,10
Bignoniceae	*Sparattosperma leucanthum*	1	11
Boraginaceae	***Cordia bicolor***	12	1,2,10,13
Burseraceae	*Dacryodes microcarpa*	1	3
Burseraceae	*Protium heptaphyllum*	3	1,3,4
Burseraceae	*Protium pilosissimum*	5	3,12,13
Burseraceae	***Protium spruceanum***	19	2,3,4,9,13
Chrysobalanaceae	*Licania apetala*	1	10,
Chrysobalanaceae	*Licania kunthiana*	1	12
Combretaceae	*Buchenavia macrophylla*	1	13
Cunoniaceae	*Lamanonia ternata*	1	13
Ebenaceae	*Diospyros sericea*	1	3
Elaeocarpaceae	*Sloanea eichleri*	8	1,9,11,12
Euphorbiaceae	*Alchornea glandulosa*	2	3
Euphorbiaceae	*Croton palanostigma*	3	1,4,11
Euphorbiaceae	*Mabea fistulifera*	6	1,2,10,12
Fabaceae	*Apuleia leiocarpa*	1	13
Fabaceae	*Enterolobium scomburkii*	1	11
Fabaceae	*Hydrochorea corymbosa*	2	1
Fabaceae	*Inga pezizifera*	7	2,3,10,11
Fabaceae	*Inga vera*	10	3,4,11,13
Fabaceae	*Machaerium myrianthum*	1	1
Fabaceae	*Ormosia paraensis*	2	1,3
Humiriaceae	***Sacoglottis guianensis***	8	1,2,4,9,12,13
Hypericaceae	*Vismia macrophylla*	2	1
Icacinaceae	*Emotum nitens*	4	13
Lauraceae	*Nectandra cuspidata*	17	1,9,10,1213
Lauraceae	*Nectandra hihua*	3	10,11,12
Lauraceae	*Ocotea acyphella*	5	1,2
Lauraceae	*Ocotea leucoxylum*	4	1,2,3,11
Lauraceae	*Ocotea velloziana*	2	9,13
Lythraceae	*Physocalymna scaberrima*	2	11,13
Malpighiaceae	*Byrsonima arthropoda*	1	2
Malpighiaceae	*Byrsonima chrysophylla*	3	2,4,13
Melastomataceae	*Bellucia grossularioides*	3	1,2
Melastomataceae	*Miconia brevipes*	7	9,10,11,12
Melastomataceae	*Miconia egensis*	1	9
Melastomataceae	*Miconia cuspidata*	9	1,2,11
Melastomataceae	*Miconia sp.*	10	9,10,11
Moraceae	*Ficus sp.*	1	9
Moraceae	*Pseudolmedia laevigata*	3	2,9,10
Moraceae	*Pseudolmedia laevis*	3	1,2,9
Myristicaceae	*Virola calophylla*	1	10

Myrtaceae	*Myrcia amazonica*	1	11
Myrtaceae	*Myrciaria dubia*	4	11,12
Myrtaceae	*Myrsine coriacea*	4	4,9,13
Olacaceae	*Minquartia guianensis*	10	1,2,3,9
Peraceae	*Chaetocarpus echinocarpus*	1	12
Polygalaceae	*Bredemeyera lucida*	1	4
Quiinaceae	*Quiina cruegeriana*	1	10
Rubiaceae	*Alibertia edulis*	1	4
Rubiaceae	*Amaioua guianensis*	16	9,10,11
Sapotaceae	*Ecclinusa ramiflora*	2	1,11
Sapotaceae	*Micropholis guyanensis*	5	2,9,11
Sapotaceae	*Micropholis venulosa*	3	3,11
Sapotaceae	*Pouteria filipes*	1	3
Sapotaceae	*Pouteria ramiflora*	3	9,11,12
Simaroubaceae	*Simarouba amara*	4	3,4,9,10
Vochysiaceae	*Qualea dicothoma*	3	13

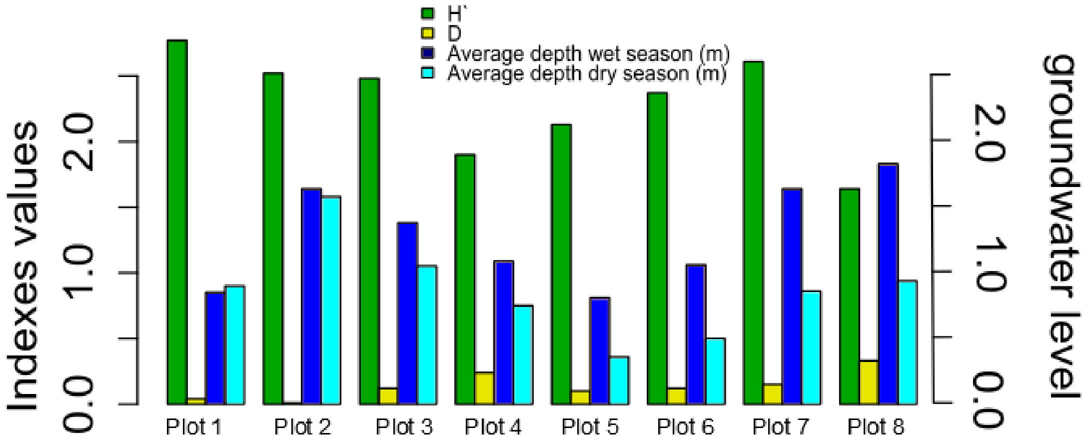

Figure 40. Shannon’s index (H), Simpson’s index (D) and variation in groundwater levels in Transect 1. Gallery forest areas are contained in Plots 1-4, and *campo de murundus* areas contained in Plots 5 to 8. Average depths are represented in meters.

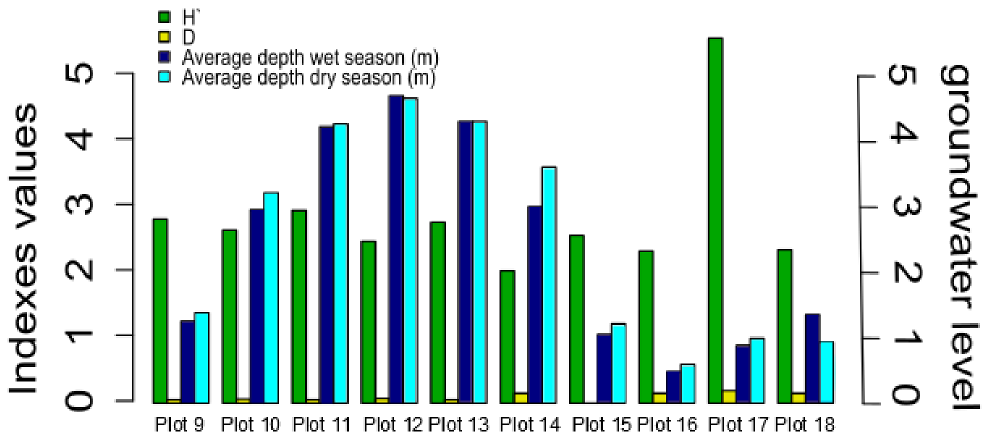

Figure 41. Shannon index (H), Simpson index (D) and variation in groundwater levels in the Transect 2. Gallery forest areas are contained in Plots 9 to 13, and *campo de murundus* are contained in Plots 14 to 18. Average depths are represented in meters.

4.3.4 Relations between plant species, groundwater level and nutrient content

To draw specific patterns of relations between the variables of interest measured in the study´s data collection, we applied a detrended correspondence analysis (DCA) to the dataset. The groundwater indicators were split into seasons and separated by amplitude, variance, average and waterlogged conditions. We wanted to understand the association of sampling sites (and plant species) with respect to groundwater and nutrient related gradients. DCA was used as an unconstrained ordination to interpret our vegetation data. It produces results, with site and species scores in ordination space, which are analysed with the subsequent clustering and environmental variables fitting methods. The clustering process is used for organizing the plant species into groups whose members are similar in some way, and together with the environmental variables fitting methods draw conclusions on the DCA results. The table 14 and 15 lists the plant species inputted in the DCA ordination, and after that a clustering procedure was made, and as the last step the table 16 lists the variables fitted into the DCA results. Each nutrient variable inserted was defined by the concentration variation across the two years of data collection.

Table 16. List of all variables used in the DCA analysis.

Aluminium all years (mg/l)	Amplitude groundwater dry season (m)
Calcium all years (mg/l)	Amplitude groundwater wet season (m)
Chloride all years (mg/l)	Average groundwater depth dry season (m)
Copper all years (mg/l)	Average groundwater depth wet season (m)
Dissolved carbon all years (mg/l)	Variance groundwater depth dry season (m)
Dissolved inorganic carbon all years (mg/l)	Variance groundwater depth wet season (m)
Dissolved nitrogen bound all years (mg/l)	Waterlogged days dry season
Dissolved organic carbon all years (mg/l)	Waterlogged days wet season
Fluoride all years (mg/l)	Distance from the river (m)
Iron all years (mg/l)	Niveau (m)
Potassium all years (mg/l)	Minimum depth wet season
Magnesium all years (mg/l)	Minimum depth dry season
Manganese all years (mg/l)	Sodium all years (mg/l)

Nitrate all years (mg/l)	Ammonium all years (mg/l)
Potassium all years (mg/l)	Silicium all years (mg/l)
Sulphide all years (mg/l)	Sulphate all years (mg/l)
Total carbon all years (mg/l)	Total inorganic carbon all years (mg/l)
Total nitrogen bound all years (mg/l)	Total organic carbon all years (mg/l)
Zinc all years (mg/l)	

In general, the DCA strongly divided the vegetation plots (1-8, and 9-18) into two groups (1-4 plus 9-13, and 5-8 plus 14-18) (Fig. 42). Basically, these groups represent the two different vegetation formations present in the study area, namely gallery forest and *campo de murundus*. The first two axes separate sites and species completely (eigenvalues of axis 1: 0.84 and axis 2: 0.51). According to long axis lengths greater than or close to 4 standard deviations (Axis 1: 5.27 and Axis 2: 3.86), a complete species turnover could be assumed at sites on the opposing ends of the axis, indicating no species in common between the plots (Jongman et al., 1995). Subsequent clustering confirmed the separation into the two groups, based in our list of plant species per plot (number of species present or absent per plot).

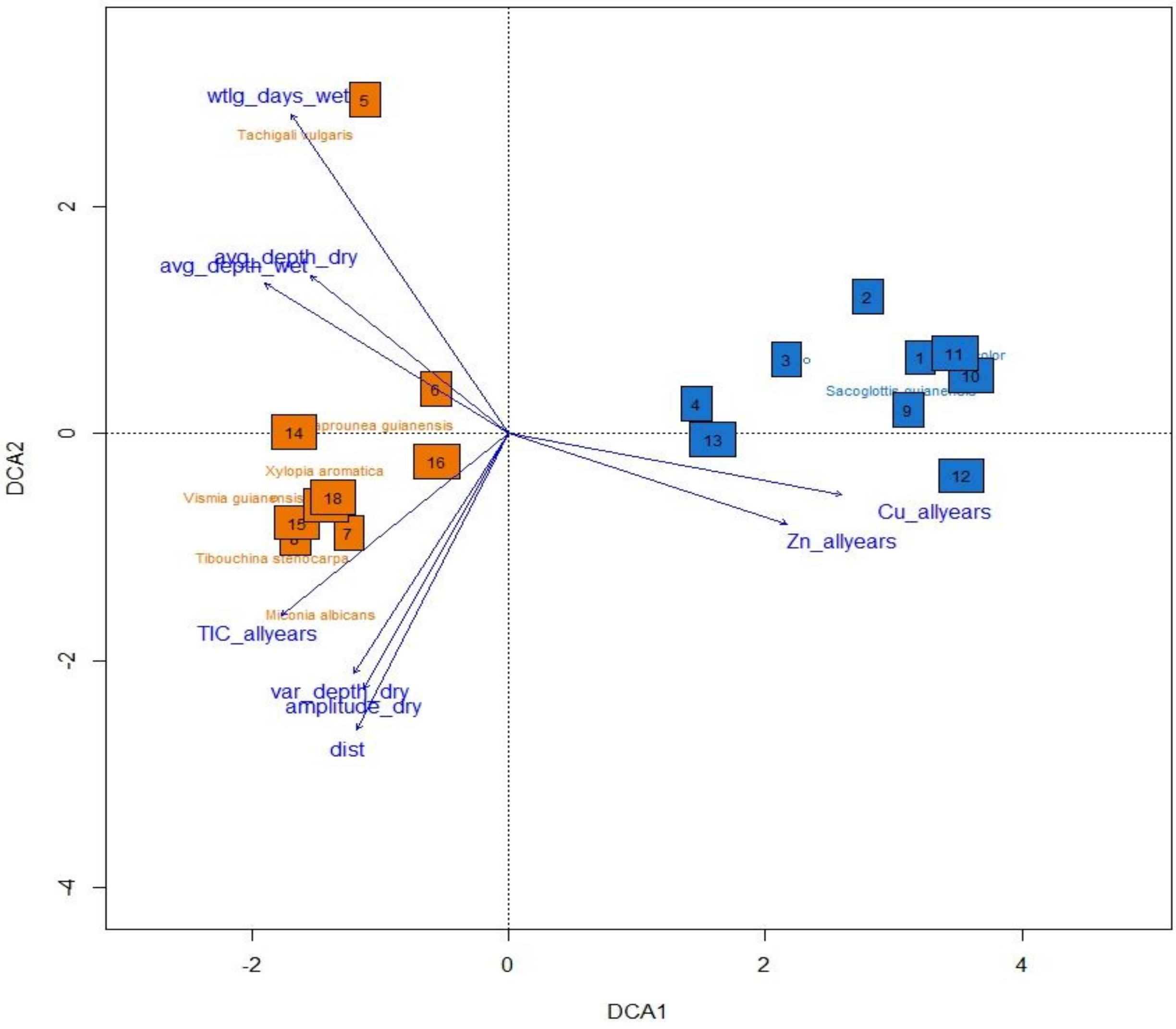

Figure 42. Analysis of detrended correspondence between plant species, transect plots and other environmental variables (distance from river, minimum and maximum groundwater level and the number of days with waterlogged soil surface). The numbers inside the squares indicate the wells within the transects, with blue denoting *campo de murundus* vegetation and orange denoting gallery forest vegetation. The values on the axis (DCA1 and DCA2) represent the gradient length in standard deviation units.

Of all the environmental variables (Table 16), some showed significant p-values in the model outcome listed in Table 17. On the lower left of DCA-1, the trees *Xylopia aromatica, Vismia guianensis, Tibouchina stenocarpa, Miconia albicans* were tightly associated with each other. The *campo de murundus* (lower left DCA-1) were correlated with total inorganic carbon, variance in dry season groundwater depth, amplitude of dry season groundwater, distance from the river. *Tachigali vulgaris* dominates the upper left quarter of the DCA-1 graph and was closely associated with high number of waterlogged days in the wet season and with plot 5. As seen on the lower right of the DCA-1 graph, no plant species were associated with Zn and Cu, however two plots were linked with Zn and Cu nutrients. On the upper right, one species is seen to be typical of the Atlantic rainforest and the Amazon rainforest, namely *Cordia bicolor*, while *Sacoglottis guianensis*, typical of the Cerrado and the Amazon rainforest, is associated with a gallery forest formation. In turn, Plots 1 to 4, and 9 to 13 were connected by two plant species, *Cordia bicolor* and *Sacoglottis guianensis*. For the DCA analysis, we modelled only a few plant species among all those surveyed in the study area, because the species are added based on their scores (weighted averages). These plants species were correlated with some environmental variables (significantly correlated) as cited in Table 17. Each arrow in the DCA model reveals the direction of the gradient, and the length of the gradient is related to the correlation between the variable and the ordination.

Table 17. Environmental variables with p-values (0.05) in the DCA analysis.

Environmental variables	**p-value**
Groundwater amplitude dry season (m, Max – Min)	0.027
Average depth dry season (m, below surface)	0.039
Average depth wet season (m)	0.022
Copper all years (average conc. mg l^{-1})	0.002
Total inorganic carbon all years (average conc. mg l^{-1})	0.035
Groundwater variance depth dry season (m)	0.041
Waterlogged days wet season (surface until 10 cm)	0.012
Zinc all years (conc. mg l^{-1})	0.022
Distance from the river (m)	0.001

5. Discussion

In this first chapter of the discussion, the results of the floristic and phytosociological characteristics of the three vegetation formations will be debated. As previously described, we focused our efforts on a highly impacted region, where the studied vegetation patches are located among intensive degraded agricultural lands. The objective was to identify and characterize the plant diversity of gallery forest, *campo de murundus* and cerrado *sensu stricto* in riparian zones of the Rio das Mortes catchment. The first two formations were located in the delimited transects 1 and 2 (Santa Luzia farm), whereas the last was located in the transect 3 and 4 (Rancho do Sol farm). These sensitive areas are key elements for the conservation of the remaining Cerrado's riparian zones, usually still holding high levels of biodiversity (Ratter et al., 1997). In addition to the gallery forest, the *campo de murundus* is also an important vegetation type of the RZ with regard to biodiversity and conservation of Cerrado plants. The results are discussed in sub-sections divided by vegetation type.

5.1 Floristic and phytosociological characteristics of the riparian zone

5.1.1 *Campo de murundus*

Similar to previous reports (Mendonça et al., 1998; Neto, 1989; Oliveira-filho, 1992), our floristic survey indicates that the *campo de murundus* is occupied mainly Cerrado-typical species, such as *Byrsonima clausseniana, Heteropterys byrsonimifolia, Styrax ferrugineus, Ouratea hexasperma,* and *Tibouchina stenocarpa.* Specifically, Marimon et al. (2012) found a minimum of 51 species, 42 genera and 27 botanical families in the *campo de murundus,* numbers that are close to our results: we found 64 species, 46 genera and 32 families. In contrast, Maricato et al. (2008) found 43 species, 35 genera and 22 families, characterizing a *campo de murundus* with lower diversity compared with this present research.

The species with the highest absolute density in our area was *Tibouchina stenocarpa*; dead individuals (not identified) counted as the group with the next highest density, followed by *Maprounea guianensis, Xylopia aromatica, Simarouba amara* and *Byrsonima clausseniana.* Our results were not in keeping with previous results (Morais et al., 2014), where the authors found *Bromelia balancae* to have the highest density, followed by *Curatela americana, Alchornea discolor, Miconia albicans, Alibertia edulis.*

Tibouchina stenocarpa is considered to be a pioneer plant (Sartor, 1994), occurring in different Cerrado formations and in riparian forests (Durigan et al, 2004), and_is associated with higher groundwater level (Pinto et al, 2005). In addition, the *Xylopia aromatica* found in our study area is one of the most important species in the *campo de murundus,* a fact confirmed by Oliveira-Filho and Ratter (1995) who reported this to be a common species in this type of vegetation. In general, the most important species in our study area were different from other surveys, except for *Xylopia aromatica*, probably due to the intensive agricultural activities occurring in our riparian zone, or to the location of a riparian zone that favors colonization with gallery forest species. The *Xylopia aromatica* is a plant species that needs intense light, developing in open habitats, mostly spreading in tree-fall gaps of rainforest or in the Cerrado vegetation (Oliveira-Filho and Ratter, 1995). Another important species we found, the *Maprounea guianensis,* is a light-demanding plant and typical pioneer species, which can survive in Cerrado and forests (semideciduous, gallery).

The genera presenting the largest number of species in our study were *Vismia* (4 species), *Miconia* (3), *Qualea* (3), *Byrsonima* (3), in contrast to the findings of Marimon et al. (2012), who reported *Paspalum* (12 species), *Byrsonima* (7), *Aristida* (7) and six species each of *Eugenia, Polygala, Rhynchospora* and *Xyris*. This difference is due to the wider range of their floristic survey, which also included the herbaceous species, while we only list the woody species. The species with highest basal areas and highest densities reported by Resende et al. (2004) were *Matayba guianensis* and *Erythroxylym suberosum,* unlike our results, where the highest basal areas were found for *Tibouchina stenocarpa, Tachigali vulgaris,* dead individuals (not identified), *Byrsonima clausseniana*, *Qualea grandiflora, Maprounea guianensis,* and *Simarouba amara*. Also, we found the highest densities for *Tibouchina stenocarpa*, dead individuals (not identified), *Maprounea guianensis, Xylopia aromatica, Simarouba amara* and *Byrsonima clausseniana.* The most dominant species reported by Resende et al. (2004) were *Copaifera langsdorffii* and *Blepahrocalyx salicifolius,* which also differed from our survey. In general, the overall diversity of plant species in the *campo de murundus* formation found in our study is different from previous findings, possibly due to the intense agricultural activities occurring in the last 30 years around the city of Campo Verde. Marimon et al. (2012) found a medium level of human impact (grazing area and burned areas) and a low level of human impact (no activity) in the *campo de murundus* of the Araguaia State Park. The studies of Resende et al. (2004) were made in a *murundus* area used as pastureland.

An analysis of the most species-rich genera reveals differences between our study and previous ones; while (Pinto et al., 2014) lists *Myrcia* (4 species), *Annona* (2 species) and *Byrsonima* (2 species), our most species-rich genera were *Qualea* (3 species), *Miconia*, (3 species), *Byrsonima* (3 species) and *Vismia* (4 species) (see also Table 2, 3, and Figure 23 in Chapter 4.1). In the same sample, the richest families were *Malpighiaceae* (6 species), *Melastomataceae* (5 species) and *Myrtaceae* (4 species), whereas, Pinto et al. (2014) found *Fabaceae* (6 species), *Myrtaceae* (6 species), *Anacardiaceae* (3 species) and *Annonaceae* (3 species). On the other hand, we found that the *Malpighiaceae* appeared as one of the most abundant botanical families, similar to Marimon et al. (2012). Also, the *Myrtaceae* family was found to be the most species-rich by Marimon et al. (2015) and Resende et al. (2004), similar to our dataset. According to Marimon et al. (2015), the *Euphorbiaceae* family is also another of the species-richest families, which also fits in with our findings.

An analysis of the biodiversity indicators reveals intriguing results. The Shannon’s index (H = 3.68 Transect 1 and 3.08 Transect 2) had higher values in Transect 1 than previous results in *campo de murundus* areas reported by Brito et al. (2008), De Morais et al. (2013), De Oliveira-Filho (1992), and Maricato et al. (2008). On the other hand, they were similar to Resende et al. (2004), who reported a Shannon’s index of 3.56 in a *campo de murundus* area located in a farm next to an asphalt road. In general, the H’ values indicated a higher diversity level compared with previous findings (Maricato et al., 2008). However, considering the normal range of diversity described by Magurran and Dornelas (2010), our level of diversity could also be considered normal.

The composition of the *campo de murundus* in the Rio das Mortes catchment is represented by several woody species, such as *Alchornea glandulosa, Alibertia edulis, Bowdichia virgilioides, Cybianthus detergens, Emmotum nitens, Maprounea guianensis, Miconia guianensis, Xylopia aromatica* (Forzza et al, 2010), that also occur in other vegetation types of Brazil. Several *campo de murundus* plant species, such as *Byrsonima pachyphylla, Connarus suberosus, Kielmeyera coriacea, Ouratea hexasperma, Qualea parviflora, Q. grandiflora*, and *Roupala montana* (Pinto et al., 2009) also occur in savanna vegetation (cerrado *sensu stricto*, cerradão*)*. Moreover, *campo de murundus* also contains plant species from other Brazilian biomes, for example *Qualea parviflora* and *Qualea grandiflora*, which can colonize Amazon rainforests, Atlantic rainforests, and Caatinga (Forzza et al, 2010). Both species are known as deciduous plants that absorb water from deeper soil layers, and were found in the *campo de murundus* (Jackson et al., 1999) probably at *murundus* elevations.

The *campo de murundus* from Rio das Mortes normally has a lower level of flooding, when compared with Araguaia river, only forming a small water layer during the wet season peak. In contrast, the *murundus* catchment on the Araguaia river (Marimon et al., 2012), is larger in size, sparser per hectare, sparser and contains a smaller number of trees and shrubs in the flooded areas (*campo limpo*). Nevertheless, the same author found a higher diversity of species and the presence of trees and shrubs in the flooded areas during the wet season in the *murundus* of Rio das Mortes (Marimon et al., 2012). The layer of water in our study area was thinner (2 to 3 cm) than that measured near the Araguaia river, which may have enabled Cerrado plants species to develop that are usually intolerant to waterlogging on the *murundus.*

In general, the *campo de murundus* has a particular environmental characteristic; the soil is waterlogged during the wet season for a period that extends from 32 to 200 days (Table 9 in Chapter 4.3), and only some plant species survive under such ecological conditions. As confirmed by Marimon et al. (2012) the *murundus* elevations and the fields (*campo limpo*) among them shape a heterogenic environment that enables specific plant species to develop in the *campo de murundus.* Despite the intensive agricultural activities, the most abundant families are the same as previous findings, confirming the typical families of the *campo de murundus.* However, the three typical species that Marimon et al. (2012) points to as characterizing a *campo de murundus* in an area with low to medium human impact (pasture and burning process), *Curatella americana, Erythroxylum suberosum, Byrsonima cydoniifolia,* were not found in our dataset. It can only be speculated that the agricultural activities occurring in the area for over 30 years have hindered the establishment of these species in the area of our study. It is also likely that the increasing isolation of this surveyed patch of vegetation due to the surrounding croplands, which are maintained by heavy machinery, has inhibited the development of vegetation.

5.1.2 Cerrado *sensu stricto*

The floristic survey of the Cerrado *sensu stricto* transect revealed a total of 97 species, 62 genera and 35 families in the area (Table 4 and 5 in Chapter 4.1). Felfili and Fagg (2007) reported similar results in the same formation, with 87 species, 65 genera and 33 families, with 23 species in common with our study. Felfili et al. (2002) found similar values in a *Cerrado sensu stricto* area in the Araguaia river valley (transitional zone between Cerrado and Amazonian) with plots of 1000 m^2. Similarly, Lima et al. (2015) found 105 species, 72 genera, and 40 families. Furthermore, Felfili et al. (2002) reported almost 5% dead individuals, which was similar to this study where 3.14% were found.

The *Fabaceae* is commonly the most species-rich family in the Cerrado (Carvalho et al., 2010), a fact confirmed by our results. In addition, the *Malpighiaceae* is also one of the most species-rich families in our dataset, confirming previous findings (Carvalho et al., 2010; Saporetti Jr et al., 2003). The *Myrtaceae* also appears in our survey as one of the most abundant botanical families, as also in Carvalho et al. (2010) and Felfili et al. (2002). Like in our study, the *Vochysiaceae* was the most abundant family reported in Lima et al. (2015). Furthermore, our results showed that *Qualea parviflora*, *Kielmeyera coriacea*, *Ourathea hexasperma* are the most important species, in line with Silva et al. (2002).

In our survey, the genera with the largest number of species were *Byrsonima* (4 species) and *Myrcia*, *Eugenia*, *Miconia*, *Qualea*, *Erythroxilum*, and *Kielmeyera* (3 species each) (Table 3 and 4 in Chapter 4.1), similar to the findings of Carvalho et al. (2010). However, their study area was located in a private Cerrado reserve, surrounded by pastures, sugar cane and eucalyptus plantations in the state of São Paulo. Our findings for richness and the Shannon's index (H = 3.25 for Transect 3 and 3.46 for Transect 4) are within the range of previous results for Cerrado *sensu stricto* areas, such as those of Fonseca and Silva Júnior (2004), though their plots sizes were bigger (1000 m^2) and located in the Brasilia Botanical Gardens.

The species composition of our study area included several woody species that occur in other vegetation types in Brazil, such as *Tapirira obtusa, Annona crassifolia*, *Tabebuia aurea, Kielmeyera coriaceae, Davilla elliptica, Caryocar brasiliense* (Forzza et al, 2010). The Cerrado *sensu stricto* has several plant species that also occur in other types of Cerrado (*cerradão, Cerrado rupestre*) formations, such as *Byrsonima coccolobifolia, Byrsonima pachyphylla, Caryocar brasiliense, Connarus suberosus, Erythroxylum suberosum, E. tortuosum, Hymenaea stignocarpa, Kielmeyera coriacea, Ouratea hexasperma, Pouteria ramiflora*, *Qualea parviflora, Q. grandiflora,* and *Roupala montana* (Pinto et al., 2009). The above-mentioned species were all found in the sampled area; this plant species heterogeneity is evidence for the well-preserved condition of the transects in terms of plant diversity (Saporetti et al., 2003).

The sampled transects presented deciduous trees that take up water from deeper soil layers, such as *Kielmeyera coriacea, Qualea grandiflora,* and *Qualea parviflora.* On the other hand, evergreen trees such as *Schefflera macrocarpa, Miconia ferruginata, Roupala Montana, Ouratea hexasperma, Sclerolobium paniculatum* take water from shallow soil layers (Jackson et al., 1999). These species form a heterogenic environmental cover that survives during the whole year. Deciduous trees are able to take water from deeper soil layers during the dry season, and evergreen trees, which take groundwater from shallow soil layers, also have phytomorphologic characteristics that help them to survive during the driest period of the year (Jackson et al., 1999). Indeed, Rawitscher (1948) found that the soil in several *cerrado sensu stricto* areas in the state of São Paulo are constantly humid at depths of about 1-5 meters.

The diversity of plant species and the H index provide evidence that the studied area is well-preserved. The quantity of species, genera and families in our dataset show a well-preserved *cerrado sensu stricto* area, even though they are surrounded by intense agricultural activity. The heterogeneity of the plants species found in our sample was typical for *cerrado sensu stricto* formations. Several species were exclusive to the Cerrado Biome, whereas some other species were from Caatinga, the Amazon rainforest and the Atlantic rainforest. The vegetation patch with *cerrado sensu stricto* in our study area is large enough to maintain several different plant species and does not suffer from the effects of heavy farm machinery working on its perimeters to the same extent as smaller patches that suffer from “edge effect” which reduces plant biodiversity (Ratter et al., 2003). Our data thus indicates a well-preserved *cerrado sensu stricto* area, due to its spatial characteristics, i. e. a size of 214.30 hectares.

5.1.3 Gallery forest

The floristic survey revealed that the gallery forest sampled for this dataset was occupied by some typical Amazon rainforest species as described by Ratter et al. (1973), such as *Aspidosperma excelsum, Buchenavia macrophylla, Connarus perrottetii, Croton palanostigma, Dacryodes microcarpa, Guatteria foliosa, Guatteria scytophylla, Inga pezizifera, Jacaranda copaia, Machaerium myrianthum, Miconia egensis, Ormosia paraensis, Pseudolmedia laevis, Sacoglottis guianensis, Virola calophylla, Xylopia amazonica,* and *Xylopia polyantha* (Forzza et al., 2010). We counted 82 species, 62 genera and 34 families in the delimited plots (see Table 6 and 7 in Chapter 4.1). Other surveys have reported different compositions, for example Barbosa et al. (2011) found less diversity with 52 species, 48 genera, and 31 botanical families. On the other hand, Silva-Júnior (2005) and Marimon et al. (2002) found a greater diversity than that in our study area, with 99 species, 88 genera and 46 families, and 129 species, 105 genera and 47, respectively. In the case of Silva-Júnior (2005), differences in the methodology can account for the results, since the author made a wider survey with 250 points per quadrants. The gallery forest in our study suffered from the intense activity of heavy machinery around the vegetation patch, since twice a year the surrounding soil is prepared for the cultivation of corn and soya. In addition, we observed ongoing selective logging within the gallery forest during the field work, which constantly disturbs vegetation cover and seed dispersal (Schleuning et al., 2011).Such degradation processes affect the recovery of vegetation and inhibit the development of secondary plant species (Salemi et al., 2013).

The genera embracing the largest number of species in our gallery forest were *Xylopia* (4 species), *Miconia* (3), *Ocotea* (3), *Protium* (3), which differed from Pereira et al. (2015) who found *Qualea* (4 species) and *Vochysia* (3) to be the most species-rich genera. The species mentioned by Felfili (1995) as having the highest basal areas, namely *Lamanonia tomentosa, Copaifera langsdorffii, Amaioua guianensis, Guatteria sellowiana,* differed from our findings, which were *Tapirira obtusa, Protium spruceanum, Nectandra cuspidata,* with only *Amaioua guianensis* in common with the cited author. This difference in species number with high basal area in the most common genera may be due to the presence of more pioneer plants species in our study area, which indicates a higher human impact from agricultural activity in our selected patches.

The species with the highest importance value index (IVI) in our study were mostly primary ones, such as *Tapira obtusa, Protium spruceanum, Nectandra cuspidata, Sacoglottis guianensis*, *Cordia bicolor* and *Amaioua guianensis*, which largely differs from previous findings (Carvalho et al., 2013a; Marimon et al., 2002; Silva-Júnior, 2005). In these studies, species such as *Nectandra nitidula, Gochnatia polymorpha, Dendropanax cuneatus, Protium heptaphyllum, Trichilia pallida, Callisthene major, Tapirira guianensis, Protium almecega, Copaifera langsdorffii, Sclerolobium paniculatum* var. *rubiginosum, Pseudolmedia laevigta, Faramea cyanea, Emmotum nitens, Lamanonia ternata, Maprounea guianensis, Diospyros obovata, Calophyllum brasiliense, Tetragastris altissima, Protium heptaphyllym, Astrocaryum vulgare* appeared with the highest importance value index. Therefore, it is possible to affirm that the Cerrado’s gallery forests have a heterogeneous plant distribution, since it is colonized by species from the Amazon and Atlantic rainforest (Oliveira-Filho and

Ratter, 1995). However, in our dataset, these differences might have been driven by the selective logging activity in the area, which contributes towards maintaining the vegetation in the first stages of recovery with a predominance of pioneer plants.

The most species-rich genera found in a previous study by Felfili (1995) were *Aspidosperma, Miconia* and *Myrcia,* which differed (except for *Miconia)* from our own study which found *Xylopia* (4 species), *Miconia* (3 species), *Ocotea* (3 species) and *Protium* (3 species) to be the most species-rich. Felfili (1995), also found *Fabaceae*, *Annonaceae, Lauraceae*, *Sapotaceae* and *Melastomataceae* to be the richest families in a gallery forest located in the Cerrado, as well as other families, namely *Myrtaceae*, *Rubiaceae*, *Apocynaceae, Vochysiaceae, Guttiferae,* and *Moraceae*. The most abundant (number of individuals) families in the present study were *Anacardiaceae, Lauraceae*, *Melastomataceae, Burseraceae* and *Fabaceae*, though Silva-Júnior (2005) found the *Leguminosae, Vochysiaceae, Rubiaceae, Anacardiaceae, Euphorbiaceae, Lauraceae, Burseraceae, Moraceae, Annonaceae, Symplocaceae* and *Cunnoniaceae* to be the most common and important families, confirming a similar presence of two families from the present study (*Anacardiaceae* and *Lauraceae)*. Marimon et al. (2002) found the *Burseraceae* to be the most abundant family, as well as the *Fabaceae,* both of which were also found to be similarly abundant in the present study. Again however, several species found in the present study area are pioneer plants, reaffirming the impact of the agricultural activities.

The Shannon index of biodiversity (H = 3.23 in Transect 1 and 3.48 in Transect 2) shows lower values than previous results from Silva-Júnior (2005) with regard to a gallery forest in Mato Grosso. On the other hand, our values were similar to Carvalho et al. (2013), who reported a Shannon index of 3.49 in a Cerrado gallery forest in São Paulo. The gallery forest in the riparian zone of the present study was contiguous with the *campo de murundus,* and is surrounded by agricultural activities. It is thought that biodiversity is decreased by intense anthropic activities, in our case by selective logging and agricultural, through which the biodiversity in our study area is similar to or lower than previous findings (Carvalho et al., 2013a; Silva-Júnior, 2005). The area studied by Carvalho et al. (2013) underwent natural regeneration during the last 40-50 years, but (like our study area) with cattle use, circulation of residents inside the area, and burning occurring next to the study plots. In contrast, the area monitored by Silva-Júnior (2005) was protected from fire and other anthropogenic disturbance for 20 years, which is the reason the H’ index was higher than for our study area.

Normally, the plant biodiversity in a gallery forest is formed by several different types of trees and large shrubs and is expected to be higher than the Cerrado itself (Ratter et al., 2003).

A key ecological feature of gallery forests is that they usually present a high level of plant diversity, since they share boundaries with rainforests, savanna formations and mesophytic forests from which they receive a diverse variety of plants species (Oliveira-Filho and Ratter, 1995). The gallery forest develops only on humid soils, spreading across the Cerrado biome and connecting the Amazon and Atlantic rainforests through plant species that colonize these formations (Ribeiro and Walter, 2008). Correspondingly, our analysis of the gallery forest study area near the Rio des Mortes confirms this strong connection with the Amazon and Atlantic rainforests, in that we found several species native from both biomes.

We did not find specialist plant species in the gallery forest, but numerous gallery forest species are habitat generalists, such as *Schefflera morototoni*, and *Protium heptaphyllum.* These two plant species were found in the study area, but only in the gallery forest, like in Oliveira-Filho and Ratter (1995). *Tapirira guianensis* and *Virola sebifera,* also considered habitat generalists, were found in both types of vegetation, i. e. gallery forest and *campo de murundus. Miconia* and *Protium* are two typical gallery forest genera; in the present study these were represented by *Miconia brevipes, M. egensis, M. cuspidata, Protium spruceanum, P. heptaphyllum* and *P. spruceanum.*

A possible methodological limitation of this study is the exclusion of herbaceous plants in the floristic and phytosociological survey. Some studies include the herbaceous plants (Munhoz and Felfili, 2007; Oliveira et al., 2008) and others do not (Carvalho et al., 2013a; Marimon et al., 2012). This is one reason for a wide divergence in the diversity index of many studies. It would have been advantagous to have included more areas with riparian zones to compare our findings in the Cerrado biome.

To conclude, the present chapter has characterized the plant distribution, structure and composition in the riparian zones located between agricultural lands in the Brazilian Cerrado. Plants species found in other *campo de murundus, cerrado stricto sensu* and gallery forest formations were also found in this study, however only our *cerrado stricto sensu* area was found to be in a well-preserved state, whereas the gallery forest was more negatively impacted by the surrounding agricultural activities. Nevertheless, the *campo de murundus* presented a higher level of biodiversity in Transect 1 that found in previous studies such as Brito et al. (2008), De Morais et al. (2013), De Oliveira-Filho (1992), and Maricato et al. (2008), despite the intense nearby agricultural activities (heavy machinery and cattle). However, *cerrado* *sensu stricto* had a higher H’ index than reported in other studies. A possible explanation for this may be the width of the riparian zone around Transects 1 and 2, which were narrower than those of the the RZ of the *cerrado sensu stricto* transects, i.e. the vegetation patches in the *cerrado sensu stricto* areas were larger than those in the gallery forest and *campo de murundus* areas. Several plant species from the Amazon and Atlantic rainforests, as well as plant species adapted to a Cerrado and Caatinga environment were found in the *campo de murundus*. The gallery forest also possessed plant species adapted to these four biomes. The *cerrado sensu stricto* had more plant species adapted to a Cerrado environment, but also some plant species adapted to the Cerrado, Caatinga, Atlantic rainforest and Amazon rainforest biomes. The Cerrado was quite heterogeneous, with several plant species adapted to the environment of other vegetation types, including plants with shallow or deeper root systems. However, the negative impact of human activity, i.e. the use of heavy farm machinery in the fields, dominates the area, even without invading the natural vegetation.

5.2 Assessment of a riparian zone as an ecosystem service provider in an agro-industrial area of the Cerrado biome[2]

This chapter discusses the hypothesis that the plant community in the riparian zone contributes to the maintenance of water quality in a catchment area impacted by surrounding intensive croplands. To do so, the water quality was monitored concurrently both inside and outside the riparian zone of Transect 1: inside its limits, which included gallery forest and *campo de murundus* vegetation types, groundwater, overflow (inside riparian zone and outside riparian zone), river discharge with baseflow and stormflow. Outside the riparian zone, the overflow was sampled in the cropland area. In addition, a floristic survey was made to characterize the type of vegetation and the plant species occurring in the study area.

The composition of plants species defines the efficiency of nutrient uptake from the soil and the water (Osborne and Kovacic, 1995). We found in the RZ of Transect 1 several individuals of *Tachigali vulgaris*, *Bowdichia virgilioides*, *Hydrochorea corymbosa*, *Ormosia paraensis,* which are species of the *Fabaceae* family (*Leguminosae*), known as nitrogen fixing plants (Soltis et al., 1995) (see in Fig. 26 in chapter 4.2). The greatest individual

---

[2] Section resulting from paper – Nóbrega, R. L. B.; Ziembowicz, T. (et al.) (shared first-authorship). Assessment of a riparian zone as an ecosystem service provider in a agroindustrial area in the Amazonian Agricultural Frontier. Target Journal: Environmental Monitoring and Assessment.

incidence in the RZ of Transect 1 was of the *Tibouchina stenocarpa* species, which belongs to a genus that is well-known for its ability to colonize intensely degraded areas, thus contributing to their recovery (Lorenzo *et al.* 1994).

In the gallery forest of Transect 1, the most abundant species was *Tapirira obtusa*, which is a pioneer plant that needs a high level of light for germination and development (Raaimakers & Lambers, 1996); it contributes to vegetation re-establishment, attracting fauna seed dispersers (insects and birds) with its small fruits (Pereira et al., 2012). Because the *Tapirira obtuse* was found to be the most frequent tree surveyed in the gallery forest and it is a pioneer species developing a secondary vegetation, and since we found several dead and juvenile trees, we can conclude that an intense regeneration process is underway (Goodale et al., 2012). In fact, the main common characteristic between the gallery forest and *campo de murundus* in Transect 1 was the predominance of pioneer species, which have ecological roles such as the recovery of a perturbed area or a degraded site, refilling canopy spaces inside the forest (Goodale et al., 2012). Like Morais et al. (2013), we also observed the *Melastomataceae* family representing the highest incidence in the *campo de murundus*. A relevant characteristic of this group is its capacity of intense regeneration in RZs, preparing the soil for the process of increasing forestation and facilitating the normal course of successional stages (Mendonça et al., 2008). Its pollen has a great viability that produces high seed quantity for germinating and propagating new plants (Domingos et al., 2003; Fava and Albuquerque, 2009); this is in keeping with our observation that this RZ of Transect 1 is under regeneration.

The plant species in the Cerrado, including several different types of *cerrado* and *campo de murundus* formations, are adapted to the high Al content, low pH and deficient nutrient content that are commonly found in the Cerrado soils (Ruggiero et al., 2002). For instance, two families found in the RZ of Transect 1 (see in Table 2 in Chapter 4.1) – *Melastomataceae* and *Rubiaceae* – have the capacity to accumulate aluminium in their leaves (Haridasan, 2000). Because of the characteristics of the soils in this region, farmers usually apply lime to reduce soil acidity and fertilizers to improve crop growth. Other nutrients, such P and S, are naturally reduced in Cerrado soils (Tinker and Nye, 2000), but due to fertilization, cropland areas show a higher content of these nutrients (Martinelli et al., 2010). In this context, the RZs play an important role in maintaining natural soil properties, as native plants of the Cerrado are adapted to these propertied and are able to regenerate without additives. Our findings agree with the observation that the vegetation and soil in the RZs form a micro-environment, where the specialized capillarity of the Cerrado lateral root plant system allows extensive contact with nutrients and their uptake by plants (Sternberg et al., 2005). Additionally, carbon and nitrogen contents are normally higher in the topsoil of the RZ, which we attribute to natural ecosystem processes in this area, such as litterfall, higher organic material decomposition, and therefore higher humus content (Parron et al., 2011).

Riparian zone patches have an important role as buffers, even when their widths are severely reduced; they work to filter the nutrients coming from the cropping land and thus help maintain water quality (Addy et al., 1999; Daniels and Gilliam, 1996; Gyawali et al., 2013; Lowrance et al., 1984; Lowrance and Sheridan, 2005; Osborne and Kovacic, 1995; Verstraeten et al., 2006; Weigelhofer et al., 2012). Normally, mature riparian zones containing forest vegetation tend to accumulate high levels of nutrients and pesticides; however, a straight patch of vegetation will perform a better filtering function of those elements when compared to a patch of grass or shrub (Aguiar et al., 2015). Results from Aguiar et al. (2015) showed that a minimum width of 36 m of woody vegetation in a south Brazilian landscape can filter pesticides. The retention capacity of RZs was around 70% to 94% in samples collected after the first rain event and right after agrochemical applications (Aguiar et al., 2015). Lowrance et al. (1984) extracted water samples from a stream every 12 hours after each rain event and subsurface water from wells along uplands fields, pastures and forests in the Little River region, Georgia, US. The authors detected a nutrient retention of 68% N, 39% Ca, 30% P, 23% Mg, 6% K in the riparian zone.

Our results showed a decrease in concentration of several elements (e.g., DIC, SO_4^{2-}, S, K, P, Mg^{2+}) during the passage of water through the RZ until it reached the stream (Fig 28 and 29 in Chapter 4.2). This was demonstrated by a reduction in DIC from the hydrological pathway overflow PLU to overflow RZ, baseflow and stormflow. Nevertheless, in the groundwater, the reduction was less than in the other pathways. The SO_4^{2-}, K, P, S and Mg showed a reduction process from overflow PLU to baseflow. On a farm in the USA, Lowrance and Sheridan (2005) also verified the capacity of RZs to retain nutrients (NO_3^-, NH_4^+ and K). These results are also in agreement with earlier findings by Parron and Markewitz (2010) in the Cerrado biome, who reported a reduction of N and P in water fluxes towards the stream going through a RZ. Concerning the higher TOC found in the water sampled inside the RZ, we attribute this to the process of organic matter decomposition, which is more intense in the RZ ecosystem and which also explains the higher carbon content in the water and soil of the RZs (Aguiar Jr. et al., 2015).

The community of plants and soil adsorption contribute towards maintaining the water quality in the riparian zone, however some routine practices in croplands are threatening the maintenance of the RZs. For example, in the present study, we verified *in locu* the common regional practice of opening the cropland area for cattle grazing during the period between two agricultural years (fallow period), which happens at the end of the dry season (Loss et al., 2012). The trampling of cattle compresses the soil, inhibits the natural regeneration of vegetation and expansion of plants roots, and reduces water infiltration (Chaichi et al., 2005; Hunke et al., 2014). Additionally, heavy agricultural machinery endangers the natural regeneration of vegetation or even destroys smaller shrubs or trees in the riparian zone (Salemi et al., 2013).

Maintaining native RZs conserves the soil properties (Hooper et al., 2005) and their ecosystem services for the water fluxes (Tabacchi et al., 2000). Hydrological processes reallocate nutrients along the soil through infiltration and runoff, influencing the vegetation composition and structure (Ravi et al., 2007). Changes in the soil's hydro-physical properties could endanger this soil-water interaction. Still, the RZ in the Rio das Mortes catchment is performing its ecological function, since several nutrients are reduced along the hydrological pathways as described in this discussion. For example, the physical conditions of the soil that provide waterlogging environments in the *campo de murundus* are known to reduce the Fe-oxides (Klink and Moreira, 2002), which may play an important role in driving soil biogeochemical processes during periods of anaerobiosis (Yang and Liptzin, 2015). Together, the soil and vegetation are responsible for maintaining ecological functions, such as filtering nutrients and sediments in this riparian zone.

Some limitations occurred in this part of the study. First, our access to other areas of the farm, which would have been relevant to the study for comparing the riparian zone of other parts of the farm along the Rio das Mortes, was denied by the farm owner. The possible period of sample collection was limited to one month, but a longer period of sampling would have been useful in order to compare nutrient concentrations in different seasons. Another limitation was the lack of control areas, one with no riparian zone vegetation and one more with vegetation for comparison between two riparian zones.

Further studies are necessary to address the efficiency of RZs using long-term analysis. Our own findings demonstrate that the groundwater in the RZ in Transect 1 often showed nutrient concentrations higher than the baseflow and stormflow, and, in some cases (i.e. TIC, DIC and Ca) also higher than the overflow in the RZ zone, resulting in a filtering effect in the groundwater stream by the substrate. We highlight that it is still uncertain what the implications of the current agricultural practices are with regard to the streamflow under baseflow conditions, due to the negative impact on the groundwater. Thus the soil-plant-atmosphere continuum needs to be addressed in a more integrated manner in future research, which should consider the effects interflow and groundwater flow have on the streamflow quality, and the role of root uptake systems, which are well-known for being complex in the Cerrado biome (Canadell et al., 1996), play in the groundwater quality.

However, we can conclude that the riparian zone contributes to the maintenance of the water quality, since the concentration of several nutrients (e.g., DIC, SO_4^{2-}, S, K, P, Mg) was reduced along the hydrological pathways from cropland to the river, because of passing through the RZ. The vegetation in the riparian zone is formed by several pioneer plants that regenerate degraded areas in the Cerrado region. More attention should focus on the capacity of the riparian zone to maintain water quality, and more studies should address these variables specifically in the Cerrado biome.

5.3 Ecohydrological relations between woody plant diversity and groundwater in the Cerrado riparian zone

In this part of the study, we aimed to assess ecological relationships between plant diversity and the groundwater level in the Cerrado Riparian Zones in order to identify possible plant indicators. Specifically, we wanted to investigate which plant species could indicate high or low groundwater level regimes, to evaluate whether groundwater nutrients are linked with vegetation types and plant species, and to determine whether groundwater table depth explains vegetation patterns of various types, and plant α-diversity. Other than surveying the plant diversity in a Rio das Mortes catchment RZ (Transects 1 and 2), we analysed groundwater nutrients and table depth during a two year period. We hypothesised that groundwater levels and their seasonal change is a main environmental factor for spatial plant distribution in RZs; that indicator plants for a groundwater regime can be identified; and that groundwater nutrient concentration might have an influence on plant diversity. As several aspects of the results have been discussed in chapter 5.1, the plant diversity factor is restrained here to the key floristic and ecological findings.

The Shannon`s index results for plant diversity showed normal values for both transects, ranging from 1.5 to 3.5 (see Fig. 40 and 41, chapter 4.3) (Magurran, 2004;

MacDonald, 2003), which indicates a normal level of plant diversity despite the area being highly impacted by agroindustry activity (heavy machinery) and selective logging. However, the H-index (Transect 1 and 2) results were lower when compared with Marimon et al. (2002), that found very high plant diversity in a Cerrado gallery forest zone surrounded by Cerrado *sensu strictu, campo sujo* and *cerradão*, without human activities affecting the area. Nevertheless, the *campo de murundus* in Transect 1 showed a similar H-index when compared with De Oliveira-Filho (1992), who surveyed this vegetation surrounded by intact Cerrado. Interestingly, Villalobos-Vega et al. (2014b) found a decrease in the H-index in waterlogged environments of the Cerrado located inside a protected area. Concerning the Simpson index, our results did not show differences between the two transects (see Fig. 40 and 41, chapter 4.3), confirming previous findings of Pinto et al. (2014) who also found no differences between woody vegetation surveyed at *campo de murundus.* Scholz et al. (2008) verified that the sharp boundary between the gallery forest and *campo de murundus* leads to a decrease in tree diversity. This is also shown through our results, where the H-index is reduced in the transition between the two vegetation types (*campo de murundus* and gallery forest) (see Fig. 40 and 41, plot 14 and 4). Moreover, our results indicated an increase in the total number of trees per ha in *campo de murundus* when compared with those of the gallery forest, characterizing an edge effect that promotes the development of specialist plant species adapted to the conditions in bordering areas (Lloyd et al., 2000; Murcia, 1995). Comparing the α-diversity of previous findings (Marimon, Felfili, & Lima, 2002; Villalobos-Vega et al., 2014), our results showed a reduction, confirming that diversity reduces in line with increased human impacts (livestock rearing and logging).

Previous findings indicated that only a few plant species can survive in the *campo de murundus* areas, as they need to be adapted to the waterlogged conditions (Marimon et al., 2012). We confirmed that few species can survive in the waterlogged conditions, and that *campo de murundus* zones can also be colonized by typical Cerrado species that do not tolerate flooding conditions. Several plant species were found in our floristic survey in the *campo de murundus*¸ such as *Maprounea guianensis, Xylopia aromatica, Vismia guianensis,* and *Tibouchina stenocarpa* - these proved to survive in well-drained soils. The *murundus* elevations provide an adequate environment for certain plants, forming “islands” in the landscape, maintaining the Cerrado trees species. These are unharmed during the wet season, as the roots are kept away from the flooded soil (Cole, 1960; Marimon et al., 2012; Neto, 1989; Oliveira-Filho et al., 1989; Ponce & Cunha, 1993).

The species *Miconia albicans* and *Tachigali vulgaris* were found in our riparian zone, colonizing the wet environment in the plain areas between the earth mounds. Cerrado woody species intensively compete with herbs in the lowlands, where the water uptake for both plant types is restrained to shallow groundwater, due to the anoxic environment caused during waterlogged conditions (Rossatto et al., 2014). The plain areas were dominated by herbaceous plants with just a few trees colonising them (see Fig. 11, Chapter 2). Tree plant species tend to be more plastic with regard to the preference of water uptake, changing from shallow to deep soil layers depending on slight variations in topography. In lowlands, herbaceous species tend to dominate the surroundings (Rossatto et al., 2014).

In general, the *campo de murundus* are characterized by flooding periods, whereby the groundwater keeps the soil saturated during the wet season. These conditions cause plant specialization and leads to a reduction in the α-diversity and increases the beta and gamma diversity, due to relief, soil, and flooding level conditions (Marimon et al 2012). Recent research performed in the *campo de murundus* zone of the Araguaia river catchment, an area submitted to constant flooding like the Rio das Mortes ecosystem, validated the notion that *campo de murundus* can also be recognized by three ecologically dominant plant species. From these three, i.e. *Curatella americana*, *Byrsonima cydoniifolia* and *Erythroxylum suberosum* (Marimon et al., 2012; Oliveira-Filho et al., 1989b), only the last species was found in our surveyed area.

In the gallery forest, the most abundant plant species were *Amaioua guianensis, Cordia bicolor, Inga vera, Minquartia guianensis, Protium spruceanum,* and *Tapirira obtusa. Amaioua guianensis* is a plant species adapted to forest formations located in Cerrado (*latu sensu*), seasonally semideciduos forest and Ombrophyllous forest (Flora Brasil, 2018). *Cordia bicolor* is a deciduous pioneer tree adapted to Ombrophyllous Forest conditions, and is distributed along the Amazon rainforest, Caatinga and Atlantic rainforest (Flora Brasil, 2018). *Inga vera* is an evergreen tree that grows in riparian forests of the Amazon rainforest, Cerrado, Atlantic rainforest and Pantanal (Flora Brasil, 2018). *Minquartia guianensis* is a emergent tree common in gallery forest (flooded or in sloped areas), developing in alluvial, acid clay or sandy soils (Nebel, 2000), as well as in Atlantic rainforest and Cerrado vegetation areas (Flora Brasil, 2018). *Protium spruceanum* is a plant species found in Amazonian and Atlantic rainforests, as well as in the Cerrado gallery forest (Oliveira-Filho and Ratter, 1995). *Tapirira obtusa* is a plant species that develops in the Amazon and Atlantic rainforests and

Cerrado. It can also be found in gallery forest, and Cerrado (*sensu lato*), seasonally semideciduous, and Ombrophyllous forests (Flora Brasil, 2018).

Gallery forest soils in Cerrado are mostly hydric or alluvial (Farias et al, 2008) and remain wet throughout the year, despite the long dry season (Oliveira-Filho & Ratter, 2002). Nevertheless, the typical dystrophic conditions of the soil, the acidity and the low nutrient content, due to the less developed nutrient cycling, defines the savanna formation in the Cerrado environment (Furley, 1999). Thus, the vegetation impacts the allocation and retention of nutrients in the soil layers, forming a dynamic process where the soil influences the vegetation, and vice-versa (Chapin, 1980; Murphy and Bowman, 2012). Moreover, the groundwater level could also be another aspect that, together with other environmental characteristics (e.g. soil humidity and nutrients content), helps to define the type of vegetation that colonizes a habitat (Zhu et al., 2012). Terrestrial ecosystems are influenced by groundwater, as they support river baseflow and root-zone soil water through drought periods (Fan et al., 2013).

Our groundwater table depth results showed that the *campo de murundus* zone presented a specific regime with seasonal variation (dry and wet season) (see Fig 30 and 31, chapter 4.3), confirming previous findings (Villalobos-Vega et al., 2014b). In both transects, the groundwater level rises during the wet season, also verified by Villalobos-Vega et al. (2014) in a private reserve with 1300 hectares. The groundwater level in the *campo de murundus* at Transect 1 (plots 5-8) was lower when compared with the gallery forest in Transect 1 (plots 1-4). This varied from zero to three meters, characterizing a waterlogged environment for around 293 days. On the other hand, the groundwater level in the *campo de murundus* at Transect 2 (plots 14-18) was higher in relation to soil surface when compared with the gallery forest in Transect 2 (plots 9-13). The difference between transects may be due to differences in slope relief, and their location. Marimon et al (2012) confirmed that *campo de murundus* in the Rio das Mortes stays flooded for a short period when compared with Rio Araguaia, but only during the wet season.

In the gallery forest of the Transect 1 (plots 1-4), the wet and dry seasons were quite similar in groundwater depth variation, maintaining very high levels without waterlogged conditions. In turn, the gallery forest of Transect 2 (plots 9-13) showed differences between wet and dry seasons, with lower groundwater levels in the dry period and higher groundwater levels in the wet period. Topographical differences may have driven these opposing results, as Transect 1 was very plain and located parallel to the river (Fig 14, chapter 2). This explains the higher groundwater level in the gallery forest plots, while Transect 2 was characterized as a sloped area and was located transversally to the river (see Fig 15, chapter 2). The higher variation of groundwater table depth was found in wells located at *campo de murundus,* except for one that was located in the gallery forest (Transect 1 and Transect 2). The groundwater variation seems to be a dominant process in *campo de murundus,* together with erosion (Neto et al., 1989).

Unfortunately, there is no clear and comparable data available in the literature on groundwater variation in Cerrado riparian zones (*campo de murundus* and gallery forest) with which we could better compare and evaluate our findings. A few studies investigated groundwater table depth variation in the Cerrado (Oliveira et al., 2015; Oliveira et al., 2016; Villalobos-Vega et al., 2014), but with methodological differences to our study. Oliveira et al (2015) investigated *campo limpo* and *cerrado sensu strictu* groundwater levels for one month only. Oliveira et al (2016) surveyed only one groundwater well during 31 months in a *cerrado sensu strictu*. Villalobos delineated the groundwater dynamics in woody savanna (*cerrado sensu strictu)* and shrubby grassland (*campo cerrado),* but did not cover gallery forest and *campo de murundus*.

The groundwater nutrient concentration was measured and analysed as a step to draw on the ecological relationships between groundwater and plant diversity in the targeted area. The sole analysis of the element concentrations in the wells and their comparisons showed statistically significant results. Interpretation is limited due to literature constraints and the lack of standard parameters to compare (Villalobos-Vega et al., 2014). The majority of the nutrient concentration studies in the Cerrado focus on the soil elements (Amorim and Batalha, 2007b; Lopes and Cox, 1977; Ruggiero et al., 2006). It is difficult to evaluate whether or not groundwater element concentrations were standard or not, and whether abnormalities or idiosyncrasies in our study area could be detected.

The results showed significant differences between the gallery forest and *campo de murundu*s hydrological pathways in the following: TC, TIC, TNb, DC, DIC, DNb, DOC, Ca, Fe, Cu, K, Mg, Mn, Cl, NH_4, NO_3, and SO_4 levels, and described in the 4.2 chapter. For example, the Ca content was higher in our samples when compared with the Brazilian National Water Agency (ANA) results in Campo Verde (rural and urban areas), as lime (calcium carbonate – $CaCO_3$) is applied in the crop area to increase the pH of the acidic soils of Cerrado (Wantzen, 2003). The Fe concentrations were lower in the study area when compared with the wells controlled by ANA. With stormflows coming from the croplands, higher nutrient loads enter the riparian zone, due to the fertiliation applied to agricultural land (Nóbrega et al., 2017; Wuana and Okieimen, 2011a). The present study found that the nitrate was higher in the gallery forest in the Transect 1, as it was closer to the agricultural fields. The *campo de murundus* zone potentially acted as a buffer for this element. The nitrate in the second transect was similar in both vegetation types, due to presence of pasture at the border. The SO_4 in the *campo de murundus* in the second transect showed higher values when compared with the first transect, probably due to the longer waterlogged days that lead to redox-processes in the soil, leading to a reduction in oxygen and an increase in sulphate production (Rodrigo and Pollard, 1962).

The findings from the ecological relationships between groundwater parameters and plant indicators rely on the outcomes of the statistical model applied to the dataset, i.e. the detrended correspondence analysis (DCA). The DCA revealed that specific environmental conditions are indicators for vegetation types or plant species, with a clear distinction between *campo de murundus* and gallery forest. Specifically, two plant species were strongly correlated with hydrological variables, eight plant species with vegetation formations, and six hydrological variables strongly correlated with vegetation formations.

In the *campo de murundus,* the groundwater table depth dynamics (variance, amplitude and average), waterlogged duration, and total inorganic carbon were hydrological variables that were correlated with this vegetation formation. One plant species (*Tachigali vulgaris)* indicated a specific hydrological regime, whereby the groundwater level reached the soil surface layer, maintaining waterlogged conditions for several months (see Fig. 42, chapter 4.3). Not only the vegetation type, but specifically the *Miconia albicans species*, was correlated with total inorganic carbon. In addition to these two species, *Tibouchina stenocarpa*, *Maprounea guianensis*, *Xylopia aromatica*, and *Vismia guianensis* were correlated with *campo de murundus.* The correlation between these six-specific species with the *campo de murundus* quadrant in the DCA results can be linked to the floristic findings, as these were the most abundant species for this formation type in the survey (see Fig. 42, chapter 4.3).

The variables of the groundwater dynamics that were related to the *campo de murundus* (average depth in the dry and wet seasons, variance depth dry season, amplitude dry season, waterlogged days) confirm the findings of Neto (1989) that described groundwater as one of main drivers for the development of *campo de murundus.* In contrast with the work of other researchers, this author argues for two opposing ecological aspects related to *campo de murundus*: at headwaters of catchment basins (the ecological environment of our study area), the groundwater is close to the surface throughout the year, but only reaches the soil surface during the wet season; at valley sides, the groundwater is close to the surface during the wet season but does not reach waterlogged conditions. The hydrological variables related with *campo de murundus* in our results suggest that, indeed, groundwater might be a key driver that shapes this vegetation formation. As the gallery forest did not show any correlation with groundwater dynamics, this could highlight a strong difference between the two vegetation types.

The total inorganic carbon related to the *campo de murundus* axis in the DCA results can be explained through the following scenario. The calcium carbonate (lime) is applied to the cropland to raise the soil pH required for fruitful cultivation (Carvalho et al., 2009) and reaches this area first during a rain event. In the nutrient content results of chapter 4.2, the TIC was found to be high in the PLU overflow but strongly reduced in the RZ overflow. This increased in the groundwater afterwards and then declined in the base- and stormflow (see Fig. 28, chapter 4.2). The effects of the application of this chemical component in the cropland might have been driven by the presence of this element in *campo de murundus* groundwater. There is a statistical relationship between the *campo de murundus* vegetation and this element, as cited in the chapter 4.2.

Our findings indicate that *Miconia albicans* is a relevant plant species in the *campo the murundus*, as it appeared in plots 7, 8, 15, 16, 17, and 18, characterized by shallow groundwater. They support previous data that found the species in a humid transition area, between the dry and wet environment in a *Vereda* vegetation of Cerrado in Minas Gerais State (Araújo et al., 2002). Additionally, the same plant species was found in waterlogged sites in a protected area in Brasília (Hoffmann, 2000). However, Haridasan (1988) affirmed that it needs deep and well-drained soils to survive, with an elevated nutrient content at the surface (Kellman, 1979). In our results, the *Miconia albicans* was not well correlated with waterlogged conditions. For this reason it is plausible that it was mostly located on the earth mounds. On the other hand, the species was correlated with total inorganic carbon. Accordingly to recent findings (Medeiros, 2006), this evergreen species produces root hairs in order to have better absorption efficiency for soil nutrients. In addition, it is well known that the absorption of inorganic carbon by plants enhances the photosynthesis process (Espie and Colman, 1986), and that carbon dioxide is necessary to produce new leaves, stems and roots, but that plants lose water in the process (Cheng et al., 2017). Nevertheless, we also cannot rule out the notion that the present results may be an indication that specific levels of TIC in the groundwater facilitate the development of this species in certain Cerrado areas, as it is a widespread plant species in the Cerrado ecosystem.

The plant species, *Tachigali vulgaris* can work as an indicator of *campo de murundus,* sites where the groundwater level reaches the soil surface layer and waterlogged conditions are maintained for several months. However, our findings do not support the literature (Lorenzi, 1992; Lemos, Pinto, Mews, & Lenza, 2013), which shows *Tachigali vulgaris* to develop in well-drained soils of transition forests, such as Cerrado gallery forest as well as other Cerrado formations. Our results indicate that high groundwater levels in *campo de murundus* can be a driver for the colonization of the *Tachigali vulgaris* plant species. The notable separation between *Tachigali vulgaris* and the other five plant species could be related to the *murundus* reliefs (two – three meters away from waterlogged environments) keeping plants that do not tolerate wet conditions in *campo de murundus.*

Tibouchina stenocarpa was found in plots 7, 8, 15, 17, and 18 of the *campo de murundus*. According to the DCA outcome, this is an indicative species of this formation, and was probably located in plain areas without waterlogged conditions, as it was not connected with a waterlogged variable. This plant species is common in the Cerrado ecosystem, and appears mostly in grasslands and riparian zones (Durigan et al., 2004). In turn, *Maprounea guianensis* is a typical plant species from the rainforest ecossystems, but still occurs in gallery forests and Cerrado formations, and normally develops in areas with an open canopy. It prefers well-drained soils with high a clay content on smooth slopes (Lorenzi, 2002), is drought tolerant, and in our research area survived in the *campo de murundus*. The *Xylopia aromatica* is a typical plant species in Cerrado *sensu strictu* (light environment) and Cerradão (shaded environment) and prefers well-drained soils (Flora Brasileira, 2018). However, it needs humid soils to germinate, and normally develops on forest edges (Cavelier et al., 1999) and alluvial terraces (Lentz, 2000). *Xylopia aromatica* was not correlated with waterlogged conditions in the DCA analysis, and for that reason could be located on the earth mounds. The *Vismia guianensis* is a plant species that colonizes abandoned agricultural areas and active pastures, and can also survive in very dry environments due to some morphological adaptations (small leaves and a thick cuticle layer) (Dias-Filho and Dawson, 1995). These species probably appeared in the *campo de murundus* colonizing the earth mounds of this area, where they can keep their roots one - two meters away from waterlogged conditions. They were also not correlated with waterlogged variables in the DCA.

The results for the gallery forest showed there was no correlation to table depth variables, but instead two specific nutrients and two plant species that characterized it (*Cordia bicolor* and *Sacoglottis guianensis*). *Cordia bicolor* survives in wet soils and perturbed areas with very bright conditions (Haston, 2011), whereas *Sacoglottis guianensis* is normally found in gallery forests and prefers well-drained soils, is drought tolerant, and can survive intense light areas (Lorenzi, 2002). These two species were among the most abundant species in the gallery forest according to the floristic findings. Notably, these two species develop in bright conditions, which can be related to the morphology of the area, with a stripe of GF whether surrounded by crops or *campo de murundus*. Although clear differences in the groundwater characteristics of the two transects were detected, mainly in Transect 1, the groundwater level was higher due to its proximity to the river, although did not reach the soil surface. In Transect 2, the groundwater level was deeper and through the DCA outcomes, no significant relationships between these dynamics and the plant species could be seen.

Through the DCA analysis (see Table 17, chapter 4.3), copper and zinc presented a significant correlation with gallery forest plots. Toribio and Romanyà (2006) found that the presence of zinc is related to the higher amount of clay in forest soils, which shows more metal retention. *Campo de murundus* have more sandy soils and therefore a lower cation exchange capacity with which to absorb the two metals in question. Previous findings support our results, showing that Zn^{2+} is considerably greater in the gallery forest soil when compared to an adjacent savanna (Geiger et al., 2011; M. Haridasan, 1985; Hoffmann et al., 2009). In waterlogged conditions, zinc is reduced to soluble Zn^{2+} and could affect the ability of plant water uptake (Hafeez et al., 2013). The reduction in the uptake of water from the soil affects the evapotranspiration, and does not lead to the development of more dense vegetation (Giambelluca et al., 2009). This could partly explain the development of the *campo de murundus* in our study area. For that reason, the low level of zinc found in could inhibit the development of a denser vegetation with higher diversity and composition.

Current literature (Nikonov, Goryainova, & Lukina, 2001; Toribio & Romanyà, 2006) reports that Cu is retained in higher quantities by acid loam soils associated with higher organic matter. This situation occurs in the gallery forest, as the DCA analysis confirmed that the copper is linked to this vegetation type. Normally, gallery forests have more organic soil matter when compared to Brazilian Cerrado vegetation (Silva et al., 2008). Other sources have shown that there is less Cu in gallery forest zones when compared with the savanna, the opposite situation to the present findings (Geiger et al., 2011; Haridasan, 1985; Hoffmann et al. 2009). Higher Cu groundwater content can be linked to higher copper content in in the gallery forest soils, due to seasonal flooding that carries pesticides and fertilizers from surrounding cropland (Wuana and Okieimen, 2011b). In the *campo de murundus,* the Cu content is very low, less than 50% of the average in soils from other regions of the world. This is, in part due to the intense and long weathering process of the Cerrado soils and a lot of leaching through the high fluctuation of the groundwater table and a low soil cation adsorption capacity (Marques et al., 2004). This is an essential element for structural plant growth and development, regulating proteins and photosynthetic functions (Yruela, 2005). Despite our model´s results, defining Cu and Zn^{2+} as two elements correlated with gallery forest, it is not possible to affirm that these two nutrients are drivers of specific plant species in this formation.

A few methodological limitations to these results can be pointed out. Regarding the groundwater depth dynamics and nutrient content. The lack of common parameters in the literature hinders the possibility of drawing a better picture of our findings, leaving them to a more descriptive approach. In addition, technical limitations, such as the number of wells and the frequency of groundwater measurements, have to be accounted for. A wider picture of the groundwater dynamic nutrient content could uncover more specific relationships between the targeted variables. Furthermore, the use of the DCA model presents limitations for the interpretation of the results, as it delineates gradients and relationships between environmental variables, but does not link causal relationships between them. Further investigations into specific ecological aspects need to be put together in a model. For the plant diversity survey, large areas and longitudinal measurements along several years could show more detailed vegetation dynamics and the differences related to diversity between areas.

The results discussed in this chapter indicate that it is feasibile to establish relationships between groundwater indicators and vegetation formation and species in the riparian zone of the Brazilian Cerrado. The main findings highlighted relationships between the groundwater table depth, TIC and *campo de murundus*, and between copper and zinc and the gallery forest. Additionally, studies that can establish causal approaches between these variables of interest may be necessary to better understand the extent to which the groundwater can shape plant diversity in the riparian zones of the Cerrado.

6. Conclusions

Within this thesis, ecological relationships between vegetation diversity and water dynamics of the groundwater and water nutrient contents of different water fluxes in a riparian zone of the Cerrado were investigated. The vegetation diversity is mainly shaped by three important ecological compartments, soil (Amorim and Batalha, 2007b; Haridasan, 2008; Pena-Claros et al., 2012), water (Y. Fan et al., 2013; Jirka et al., 2007; Lowry et al., 2011; Villalobos-Vega et al., 2014a) and climate (Dale et al., 2001; Laurance, 2004). It is well known that nutrients and water in the soil are essential for the development of several different types of vegetation, depending on the quantity of available nutrients and water necessary for each type of formation (Haridasan, 2008; Villalobos-Vega et al., 2014a). Nevertheless, groundwater dynamics play a crucial role in the biodiversity and density of plant species within ecosystems (Y. Fan et al., 2013; Villalobos-Vega et al., 2014b). Groundwater levels in riparian zones of the Cerrado are particularly interesting, as they are drivers of *campo de murundus* vegetation (a type of Cerrado). Furthermore, riparian zones provide the human societies with several ecosystem services, that maintain the environmental qualities related to water, soil, and microclimates. These zones also filter pollutants from croplands, regulate water flow, fauna corridors, habitat for animals and plants, controlling floods, and recreation. Vegetation and groundwater were the main focus of this thesis, and for that purpose we selected a riparian zone located in the Cerrado ecosystem within an agricultural landscape. The main objective was to understand if groundwater dynamics and nutrient concentrations in different water paths is linked with plant diversity and vegetation types in the RZ. Another question was whether the riparian zone in the agricultural landscape plays a role in the maintenance of water quality.

The floristic analysis showed that RZ vegetation types, gallery forest and *campo de murundus* zones could be differentiated between through the presence of different plant species dominating the two vegetation types. Additionally, the *campo de murundus* zone presented a high level of biodiversity, despite plant and animal-based agricultural activities in the area. The vegetation presented some dominant plants, such as *Tibouchina stenocarpa, Tachigali vulgaris, Byrsonima clausseniana, Maprounea guianensis, Xylopia aromatica,* and *Simarouba amara*. Regarding the *Cerrado sensu strictu* zone, we verified that the vegetation was well-preserved, despite the cropland surrounding the area. The plant species representing this vegetation consisted of the following: *Davilla elliptica, Tachigali vulgaris, Roupala* *montana, Cybianthus detergens, Kielmeyera coriacea, Myrcia dealbata, Qualea parviflora,* and *Ouratea hexasperma.* The gallery forest zone had the lowest level of biodiversity, potentially due to its surroundings including intense agricultural activities and selective logging. The vegetative formation of this zone was characterized by *Tapira obtusa, Protium spruceanum, Nectandra cuspidata, Sacoglottis guianensis, Cordia bicolor,* and *Amaioua guianensis.*

We also assessed the water quality of one of the targeted riparian zones by comparing the nutrient content in samples of different hydrological pathways. Our study showed that the riparian zone is an ecosystem service provider that maintains the plant biodiversity and water quality. In the riparian zone, we identified a high level of plant diversity with plant physiognomies of several tropical vegetation types, such as the Amazonian and Atlantic rainforests. The majority of plants in the area were pioneer species, which improve and recover altered environments. However, soil management practices in this region, such as liming and fertilizer application, can result in substantial negative impacts in the regeneration of native species from degraded areas and the surroundings of riparian zones. The maintenance of soil´s hydro-physical properties in riparian zones provide important ecosystem services directly connected to water pathway dynamics. In this respect, we found overflow water from cropland to have the highest water nutrient concentrations, mostly related to inorganic carbon and fertilizers. We observed that these concentrations became lower as the water fluxes were closer to the stream within the riparian vegetation and further away from the agricultural sites.

We also addressed the groundwater dynamics and nutrient content, defining, together with the plant species distribution in the *campo de murundus* and gallery forest zones, some ecological conditions in the RZ`s. Through the floristic survey and with the hydrological parameters in mind, the DCA analysis defined six species related to the *campo de murundus* zone: *Tachigali vulgaris, Maprounea guianensis, Xylopia aromatica, Vismia guianensis, Tibouchina stenocarpa* and *Miconia albicans*. Two can be linked to the gallery forest zone, *Cordia bicolor* and *Sacoglottis guianensis. Tachigali vulgaris* was linked to waterlogged days during the wet season, characterizing the waterlogged environment. The five other species from *campo de murundus* possibly colonise specific murundus reliefs, so that their roots do not suffer from waterlogged conditions. In the gallery forest, *Cordia bicolor* and *Sacoglottis guianensis*, these species did not survive in the *campo de murundus,* despite being able to grow in wet environments of tropical forests. It seems that they tolerate over flooding but not extended periods of waterlogged soil conditions.

Some groundwater nutrients were linked with *campo de murundus* and gallery forest vegetation types, such as total inorganic carbon in the *campo de murundus* zone, and copper and zinc in the gallery forest zone. Nevertheless, further research is needed to confirm whether nutrients can define types of vegetation in the Cerrado and other biomes, and how this can be related to plant morphology and ecophysiology. In addition, groundwater table depth and seasonal changes delineate patterns of plant diversity in the Cerrado's riparian zones. Longer investigation periods for the hydroecological drivers of plant diversity and vegetation types may improve how groundwater dynamics and nutrient content affect the distribution of plant species in this tropical landscape.

Finally, the importance of biodiversity in riparian zones is not only related to the gallery forest, but also to the *campo de murundus* zone. This unique type of Cerrado vegetation defines a special landscape, with earth mounds forming islands of Cerrado trees. Some *campo de murundus* zone plants have special adaptations to waterlogged conditions. Furthermore, the conservation and protection of the riparian zones in the Cerrado biome must be redefined, as the last changes in the Brazilian Forest Code reduced the legal minimum required width of vegetation along the rivers, which could negatively impact the *campo de murundus* zone. The reduction of the riparian vegetation could affect the efficiency of filtering the water that flows from the surroundings areas, in rural and urban landscapes. Moreover, several plants species typical for riparian vegetation are under threat of extinction due to deforestation. This demonstrates the necessity for more in-depth studies on the ecological role of vegetation in ecosystem services as well as better protection measures.

References

Addy, K.L., Gold, a. J., Groffman, P.M., Jacinthe, P. a., 1999. Ground Water Nitrate Removal in Subsoil of Forested and Mowed Riparian Buffer Zones. J. Environ. Qual. 28, 962.

Aguiar, T.R., Rasera, K., Parron, L.M., Brito, A.G., Ferreira, M.T., 2015. Nutrient removal effectiveness by riparian buffer zones in rural temperate watersheds: The impact of no-till crops practices. Agric. Water Manag. 149, 74–80.

Aguiar Jr., T.R., Bortolozo, F.R., Hansel, F.A., Rasera, K., Ferreira, M.T., 2015. Riparian buffer zones as pesticide filters of no- till crops. Environ. Sci. Pollut. Res. 22, 10618–10626.

Amorim, P.K., Batalha, M.A., 2007a. Soil-vegetation relationships in hyperseasonal cerrado, seasonal cerrado, and wet grassland in Emas National Park (central Brazil). Acta Oecologica 32, 319–327.

Amorim, P.K., Batalha, M.A., 2007b. Soil-vegetation relationships in hyperseasonal cerrado, seasonal cerrado, and wet grassland in Emas National Park (central Brazil). Acta Oecologica 32, 319–327.

AGÊNCIA NACIONAL DE ÁGUAS (Brasil) (ANA). HidroWeb: sistemas de informações hidrológicas. Disponível em: . Acesso em: 31 novembro 2017.

Araújo, G.M., Barbosa, A.A.A., Arantes, A.A., Amaral, A.F., 2002. Composição florística de veredas no Município de Uberlândia , MG. Rev. Bras. Botânica 25, 475–493.

Araujo Neto, M.D. de, Furley, P.A., Haridasan, M., Johnson, C.E., 1989. The Murundus of the Cerrado Region of Central. J. Trop. Ecol. 2, 17–35.

Barbosa, D.C.D.F., Marimon, B.S., Lenza, E., Marimon Junior, B.H., Oliveira, E.A. De, Maracahipes, L., 2011. Estrutura da vegetação lenhosa em dois fragmentos naturais de florestas inundáveis (impucas) no Parque Estadual do Araguaia, Mato Grosso. Rev. Árvore 35, 457–471.

Binswanger, H.P., 1991. Brazilian policies that encourage deforestation in the Amazon. World Dev. 19, 821–829.

Boaventura, G.R., De Freitas, A.L.S., 2005. Inorganic Parameters as Water Qualitz Indicators in 135–151.

Bond, W.J., 2010. Do nutrient-poor soils inhibit development of forests ? A nutrient stock analysis 47–60.

Brando, P.M., Coe, M.T., DeFries, R., Azevedo, A.A., 2013a. Ecology, economy and management of an agroindustrial frontier landscape in the southeast Amazon. Philos. Trans. R. Soc. B Biol. Sci. 368, 20120152–20120152.

Brando, P.M., Coe, M.T., DeFries, R., Azevedo, A.A., 2013b. Ecology, economy and management of an agroindustrial frontier landscape in the southeast Amazon. Philos. Trans. R. Soc. B Biol. Sci. 368, 20120152–20120152.

Brito, E.R., Martins, S.V., Oliveira-Filho, A.T., Silva, E., Silva, A.F. Da, 2008. Estrutura fitossociológica de um fragmento natural de floresta inundável em área de Campo Sujo Lagoa da Confusão Tocantins.pdf. Acta Amaz. 38, 379–386.

Cabral, O.M.R., da Rocha, H.R., Gash, J.H., Freitas, H.C., Ligo, M.A.V., 2015. Water and energy fluxes from a woodland savanna (cerrado) in southeast Brazil. J. Hydrol. Reg. Stud. 4, 22–40.

Caldwell, M.M., Dawson, T.E., Richards, J.H., 1998. Hydraulic lift: Consequences of water efflux from the roots of plants. Oecologia 113, 151–161.

Calinski, T., Harabasz, J., 1974. Communications in Statistics A dendrite method for cluster analysis. Commun. Stat. 3, 1–27.

Campos, J.E.G. (Universidade de B., 2004. Hidrogeologia do Distrito Federal : bases para a gestão dos recursos hídricos subterrâneos v. 34, .

Canadell, J., Jackson, R.B., Ehleringer, J.B., Mooney, H. a., Sala, O.E., Schulze, E.-D., 1996. Maximum rooting depth of vegetation types at the global scale. Oecologia 108, 583–595.

Carbo, L., Souza, V., Dores, E.F.G.C., Ribeiro, M.L., 2008. Determination of pesticides multiresidues in shallow groundwater in a cotton-growing Region of Mato Grosso, Brazil. J. Braz. Chem. Soc. 19, 1111–1117.

Carrera-Hernández, J.J., Smerdon, B.D., Mendoza, C.A., 2012. Estimating groundwater recharge through unsaturated flow modelling : Sensitivity to boundary conditions and vertical discretization 453, 90–101.

Carvalho, J.L.N., Carlos Eduardo Pelegrino, C., Feigl, B.J., Píccolo, M. de C., Godinho, V. de P., Herpin, U., Cerri, C.C., 2009. Conversion of cerrado into agricultural land in the south-western Amazon: carbon stocks and soil fertility. Sci. Agric. 66, 233–241.

Carvalho, M.B., Bernacci, L.C., Coelho, R.M., 2013a. Floristic and phytosociology in a physiognomic gradient of riverine forest in Cerrado, Campinas, SP. Biota Neotrop. 13, 110–120.

Carvalho, M.B., Bernacci, L.C., Coelho, R.M., 2013b. Floristic and phytosociology in a physiognomic gradient of riverine forest in Cerrado, Campinas, SP. Biota Neotrop. 13, 110–120.

Carvalho, M.B., Ishara, K.L., Maimoni-Rodella, R.C.S., 2010. Vascular flora of a cerrado sensu stricto remnant in Pratania, state of Sao Paulo, southeastern Brazil. Check List 6, 350–357.

Carvalho, F.M. V, De Marco, P., Ferreira, L.G., 2009. The Cerrado into-pieces: Habitat fragmentation as a function of landscape use in the savannas of central Brazil. Biol. Conserv. 142, 1392–1403.

Casara, K.P., Vecchiato, A.B., Lourencetti, C., Pinto, A.P., Dores, E.F.G.C., 2012. Environmental Dynamics of Pesticides in the Drainage Area of the São Lourenço River Headwaters, Mato Grosso State, Brazil 23, 1719–1731.

Castro, A.A.A.J.F., Martins, F.R., Tamashiro, J.Y., Shepherd, G.J., 1999. How Rich is the Flora of Brazilian Cerrados ? All use subject to JSTOR Terms and Conditions OF Brazilian Cerrado? How Rich is the Flora 86, 192–224.

Cavelier, J., Aide, T.M., Dupuy, J.M., Eusse, A., Santos, C., 1999. Long-term effects of deforestation on soil properties and vegetation in a tropical lowland forest in Colombia. Ecotropicos 12, 57–68.

Chaichi, M.R., Saravi, M.M., Malekian, A., 2005. Effects of Livestock Trampling on Soil

Physical Properties and Vegetation Cover (Case Study: Lar Rangeland, Iran). Int. J. Agric. Biol.

Chapin, F.S., 1980. the Mineral Nutrition of Wild Plants 11, 233–260.

Cheng, L., Zhang, L., Wang, Y.P., Canadell, J.G., Chiew, F.H.S., Beringer, J., Li, L., Miralles, D.G., Piao, S., Zhang, Y., 2017. Recent increases in terrestrial carbon uptake at little cost to the water cycle. Nat. Commun. 8.

Cole, M.M., 1960. Cerrado, Caatinga and Pantanal: The Distribution and Origin of the Savanna Vegetation of Brazil. Geogr. J. 126, 168–179.

Conradi, T., Kollmann, J., Management, E., 2016. Species pools and environmental sorting control different aspects of plant diversity and functional trait composition in recovering grasslands.

Cooper, J.R., Gilliam, J.W., Daniels, R.B., Robarge, W.P., 1987. Riparian areas as filters for agricultural sediment. Soil Sci. Soc. Am. J. 51, 416–420.

Cruz Ruggiero, P.G., Batalha, M.A., Pivello, V.R., Meirelles, S.T., 2002a. Soil-vegetation relationships in cerrado (Brazilian savanna) and semideciduous forest, Southeastern Brazil. Plant Ecol. 160, 1–16.

Cruz Ruggiero, P.G., Batalha, M. a., Pivello, V.R., Meirelles, S.T., 2002b. Soil-vegetation relationships in cerrado (Brazilian savanna) and semideciduous forest, Southeastern Brazil. Plant Ecol. 160, 1–16.

Curtis, J.T., McIntosh, R.P., 1951. An Upland Forest Continuum in the Prairie-Forest Border Region of Wisconsin. Ecology 32, 476–496.

Dale, V.H., Joyce, L. a, Mcnulty, S., Neilson, R.P., Ayres, M.P., Flannigan, M.D., Hanson, P.J., Irland, L.C., Lugo, a E., Peterson, C.J., Simberloff, D., Swanson, F.J., Stocks, B.J., Wotton, B.M.C.-A.C.C.N.-P. 813564, P, R., P, M., 2001. Climate change and forest disturbances. Bioscience 51, 723–734 ST–Climate change and forest disturbanc.

Daniels, R.B., Gilliam, J.W., 1996. Sediment and Chemical Load Reduction by Grass and Riparian Filters. Soil Sci. Soc. Am. J.

De Cáceres, M., Legendre, P., Moretti, M., 2010. Improving indicator species analysis by combining groups of sites. Oikos 119, 1674–1684.

De Morais, R.F., Da Silva, E.C.S., Lema Metelo, M.R., De Morais, F.F., 2013. Composição florística e estrutura da comunidade vegetal em diferentes fitofisionomias do Pantanal de Poconé, Mato Grosso. Rodriguesia 64, 775–790.

De Oliveira-Filho, A.T., 1992a. Floodplain “murundus” of Central Brazil: evidence for the termite-origin hypothesis. J. Trop. Ecol. 8, 1–19.

De Oliveira-Filho, A.T., 1992b. The vegetation of Brazilian “murundus” – the island-effect on the plant community. J. Trop. Ecol. 8, 465.

De Steven, D., Lowrance, R., 2011. Agricultural conservation practices and wetland ecosystem services in the wetland-rich Piedmont-Coastal Plain region. Ecol. Appl. 21, 3–17.

Dias-Filho, M.B., Dawson, T.E., 1995. Physiological Responses to Soil Moisture Stress in Two Amazonian Gap- Invader Species Author (s): M . B . Dias-Filho and T . E . Dawson Published by : British Ecological Society Stable URL :

http://www.jstor.org/stable/2390567 Accessed : 11-04-2016 05 : 9, 213–221.

Domingos, M., Klumpp, A., Rinaldi, M.C.S., Modesto, I.F., Klumpp, G., Delitti, W.B.C., 2003. Combined effects of air and soil pollution by fluoride emissions on Tibouchina pulchra Cogn., at Cubatao, SE Brazil, and their relation with aluminium. Plant Soil 249, 297–308.

Dores, E.F.G.C., Carbo, L., Ribeiro, M.L., De-lamonica-freire, E.M., 2008. Pesticide Levels in Ground and Surface Waters of Primavera do Leste Region , Mato Grosso , Brazil 46, 585–590.

Dosskey, M.G., 2001. Toward quantifying water pollution abatement in response to installing buffers on crop land. Environ. Manage. 28, 577–598.

Durigan, G.; Baitelo, J. B.; Franco, G. A. D. C. & Siqueira, M. F. 2004. Plantas do cerrado paulista: imagens de uma paisagem ameaçada. Páginas & Letras, São Paulo, 475p.

Eiten, G., 1972. The cerrado vegetation of Brazil. Bot. Rev. 38, 201–341.

Espie, G.S., Colman, B., 1986. Inorganic carbon uptake during photosynthesis. Plant Physiol. 80, 863–869.

Fan, Y., Li, H., Miguez-Macho, G., 2013. Global patterns of groundwater table depth. Science (80-.). 339, 940–943.

Fan, Y., Li, H., Miguez-Macho, G., 2013. Global Patterns of Groundwater Table Depth. Science (80-.). 339, 940–943.

Farias, M.F.R., Carvalho, A.P.F., Martins, E.S., Carvalho Júnior, O.A., Reatto, A. & Gomes, R.A.T. 2008. Levantamento de solos do Parque Nacional de Brasília, escala 1:50.000. EMBRAPA, Cerrados, Planaltina.

Fava, C.L.F., Albuquerque, M.C. de F., 2009. Germinacao de sementes de Tibouchina stenocarpa (DC.) Cogn. em funcao da temperatura e substrato 2, 347–352.

Felfili, J., Nascimento, A.R.T., Fagg, C.W., Meirelles, E.M., 2007. Floristic composition and community structure of a seasonally deciduous forest on limestone outcrops in Central Brazil 611–621.

Felfili, J.M., 1995. Diversity, structure and dynamics of a gallery forest in central Brazil. Vegetatio 117, 1–15.

Felfili, J.M., Fagg, C.W., 2007. Floristic composition, diversity and structure of the “cerrado” sensu stricto on rocky soils in northern Goiás and southern Tocantins, Brazil. Rev. Bras. Botânica 30, 375–385.

Felfili, J.M., Nogueira, P.E., Marimon, B.S., Delitti, W.B.C., 2002. Composição florística e fitossociologia do cerrado 103. Ecologia 16, 103–112.

Ferreira-Júnior, W.G., Schaefer, C.E.G.R., Cunha, C.N., Duarte, T.G., Chieregatto, L.C., Carmo, F.M.S., 2016. Flood regime and water table determines tree distribution in a forest-savanna gradient in the Brazilian pantanal. An. Acad. Bras. Cienc. 88, 719–731.

Flora do Brasil 2020 under construction. Jardim Botânico do Rio de Janeiro. Available at: < http://floradobrasil.jbrj.gov.br/ >. Accessed on: 12 Feb. 2018

Fonseca, M.S. da, Silva Júnior, M.C. da, 2004. Fitossociologia e similaridade florística entre trechos de Cerrado sentido restrito em interflúvio e em vale no Jardim Botânico de

Brasília, DF. Acta Bot. Brasilica 18, 19–29.

Forzza RC, Leitman PM, Costa AF, Carvalho AA Jr, Peixoto AL, Walter BMT, Bicudo C, Zappi D, Costa DP, Lleras E et al. 2010. Introdução in Lista de Espécies da Flora do Brasil. Jardim Botânico do Rio de Janeiro, Brazil.

Fremier, A.K., Kiparsky, M., Gmur, S., Aycrigg, J., Craig, R.K., Svancara, L.K., Goble, D.D., Cosens, B., Davis, F.W., Scott, J.M., 2015. A riparian conservation network for ecological resilience. Biol. Conserv. 191, 29–37.

Furley, A., 2007. Tropical savannas and associated forests : vegetation and plant ecology 31, 203–211.

Furley, P., 1999. The nature and diversity of neotropical savanna vegetation with particular reference to the Brazilian cerrados. Glob. Ecol. Biogeogr. 8, 223–241.

Garrastazú, M.C., Mendonça, S.D., Horokoski, T.T., Cardoso, D.J., Rosot, M.A.D., Nimmo, E.R., Lacerda, A.E.B., 2015. Carbon sequestration and riparian zones: Assessing the impacts of changing regulatory practices in Southern Brazil. Land use policy 42, 329–339.

Gaspar, M.T.P., Campos, J.E.G., 2007. O Sistema Aqüífero Urucuia 37, 216–226.

Geiger, E.L., Gotsch, S.G., Damasco, G., Haridasan, M., Franco, A.C., Hoffmann, W.A., 2011. Distinct roles of savanna and forest tree species in regeneration under fire suppression in a Brazilian savanna. J. Veg. Sci. 22, 312–321.

Gerold, G., 2017. Impacts of Carbon-Optimised Land Use Management in Southern Amazonia - Multi-Disciplinary Perspectives: an introduction. Erbkunde 71, 171–175.

Gerold, G., Jungkunst, H.F., Wantzen, K.M., Amorim, R.S.S., Couto, E.G., Madari, B., 2014. Interdisciplinary Analysis and Modeling of Carbon-Optimized Land Management Strategies for Southern Amazonia, Carbiocial Status Conference in Cuiabá, October 7-8, 2013.

Giambelluca, T.W., Scholz, F.G., Bucci, S.J., Meinzer, F.C., Goldstein, G., Hoffmann, W. a., Franco, A.C., Buchert, M.P., 2009. Evapotranspiration and energy balance of Brazilian savannas with contrasting tree density. Agric. For. Meteorol. 149, 1365–1376.

Goldstein, G., Meinzer, F.C., Bucci, S.J., Scholz, F.G., Franco, A.C., Hoffmann, W. a, 2008. Water economy of Neotropical savanna trees: six paradigms revisited. Tree Physiol. 28, 395–404.

Goodale, U.M., Ashton, M.S., Berlyn, G.P., Gregoire, T.G., Singhakumara, B.M.P., Tennakoon, K.U., 2012. Disturbance and tropical pioneer species: Patterns of association across life history stages. For. Ecol. Manage. 277, 54–66.

Google Maps. n/d. [Mato Grosso State location – Campo Verde city location] Retrieved October 7, 2017, from https://www.google.de/maps/

Greaver, T.L., Sternberg, L.S.L., 2007. Fluctuating deposition of ocean water drives plant function on coastal sand dunes. Glob. Chang. Biol.

Gregory, S. V., Swanson, F.J., McKee, W.A., Cummins, K.W., 1991. An Ecosystem Perspective of Riparian Zones. Bioscience 41, 540–551.

Gücker, B., Boechat, I.G., Giani, A., 2009. Impacts of agricultural land use on ecosystem structure and whole-stream metabolism of tropical Cerrado streams 2069–2085.

Gyawali, S., Techato, K., Yuangyai, C., Musikavong, C., 2013. Assessment of Relationship between Land uses of Riparian Zone and Water Quality of River for Sustainable Development of River Basin, A Case Study of U-Tapao River Basin, Thailand. Procedia Environ. Sci. 17, 291–297.

Hafeez, B., Khanif, Y.M., Saleem, M., 2013. Role of Zinc in Plant Nutrition- A Review 3, 374–391.

Haridasan, M., 2008. Nutritional adaptations of native plants of the cerrado biome in acid soils. Brazilian J. Plant Physiol. 20, 183–195.

Haridasan, M., 2000. Nutricao Mineral de Plantas Nativas do Cerrado. Rev. Bras. Fisiol. Veg. 12, 54–64.

Haridasan, M. 1988. Performance of Miconia albicans (SW.) Triana, an aluminium accumulating species, in acidic and calcareous soils. Communications in Soil Science and Plant Analysis 19. 1091-1103.

Haridasan, M., 1985. Accumulation of nutrients by eucaliptus seedlings from acidic and calcareous soils of the Cerrado region of Central Brazil. Plant Soil 5, 35–45.

Haston, E. (2011). Trees of Panama and Costa Rica. Condit R., Pérez R. & Daguerre N. Princeton & Oxford, Princeton University Press. 494 p.

Hawes, E., Smith, M., 2005. Riparian Buffer Zones: Functions and Recommended Widths. Yale Sch. For. Enviromental Stud. 15 pp.

Hoffmann, W., 2000. Post-Establishment Seedling Success in the Brazilian Cerrado: A Comparison of Savanna and Forest Species. Biotropica 32, 62–69.

Hoffmann, W.A., Adasme, R., Haridasan, M., Carvalho, M.T. de, Geiger, E.L., Pereira, M.A.B., Gotsch, S.G., Franco, A.C., 2009a. Tree topkill , not mortality , governs the dynamics of savanna-forest boundaries under frequent fire in central Brazil. Ecology 90, 1326–1337.

Hoffmann, W.A., Adasme, R., Haridasan, M., Carvalho, M.T. de, Geiger, E.L., Pereira, M.A.B., Gotsch, S.G., Franco, A.C., 2009b. Tree topkill , not mortality , governs the dynamics of savanna – forest boundaries under frequent fire in central Brazil 90, 1326–1337.

Hoffmann, W.A., Jackson, R.B., 2000. Vegetation – Climate Feedbacks in the Conversion of Tropical Savanna to Grassland.

Hooper, D.U., Chapin III, F.S., Ewel, J.J., 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecol. Monogr. 75, 3–35.

Hopkins, A., 1992. Ecological processes at the forest–savanna boundary. In: Furley et al. (Eds.), Nature and Dynamics of Forest Savanna Boundaries. Chapman & Hall, London, pp. 21–34.

Hunke, P., Roller, R., Zeilhofer, P., Schröder, B., Mueller, N., 2014. Soil changes under different land-use in the Cerrado of Mato Grosso, Brazil. GEODRS.

Huston, M., 2005. The three phases of land-use change: implications for biodiversity. Ecol. Appl. 15, 1864–1878.

IBGE – Instituto Brasileiro de Geografia e Estatística. Pesquisa Nacional por Amostra de Domicílios. Síntese dos Indicadores de 2009. Rio de Janeiro: IBGE; 2010 [acesso em 4 dez 2017]. Disponível em: www.ibge.com.br

IBGE. 2009. [Brazilian soils] Retrevied November 4, 2017, from https://mapas.ibge.gov.br/bases-e-referenciais/cartas-tematicas.html

IBGE. 2004. [Brazilian biomes] Retrevied November 4, 2017, from https://mapas.ibge.gov.br/bases-e-referenciais/cartas-tematicas.html

IBGE. 2002. [Brazilian climate] Retrevied November 4, 2017, from https://mapas.ibge.gov.br/bases-e-referenciais/cartas-tematicas.html

IBGE. 2000. [Brazilian river basins] Retrevied November 4, 2017, from https://mapas.ibge.gov.br/bases-e-referenciais/cartas-tematicas.html

Iglesias, M., Uhlein, A., 2008. Estratigrafia Do Grupo Bambuí Na Serra Do Jaíba , 16, 21–27.

Jackson, P.C., Meinzer, F.C., Bustamante, M., Goldstein, G., Franco, a, Rundel, P.W., Caldas, L., Igler, E., Causin, F., 1999. Partitioning of soil water among tree species in a Brazilian Cerrado ecosystem. Tree Physiol. 19, 717–724.

Jirka, S., Mc Donald, A.J., Johnson, M.S., Feldpausch, T.R., Couto, E.G., Riha, S.J., 2007. Relationships between soil hydrology and forest structure and composition in the southern Brazilian Amazon 183–194.

Jongman, R.H.G., Ter Braak, C.J.F., Van Tongeren, O.F.R., 1995. Data Analysis in Community and Landscape EcoLogy.

Kellman, M., 1979. Soil enrichment by Neotropical Savanna trees. J. Ecol. 67, 565–577.

Klink, C.A., Machado, R.B., 2005. Conservation of the Brazilian Cerrado.pdf 19, 707–713.

Klink, C.A., Moreira, A.G., 2002. Past and current human occupation, and land use, The cerrados of Brazil: ecology and natural history of a neotropical savanna.

Koirala, S., Jung, M., Reichstein, M., de Graaf, I.E.M., Camps-Valls, G., Ichii, K., Papale, D., Ráduly, B., Schwalm, C.R., Tramontana, G., Carvalhais, N., 2017. Global Distribution of groundwater-vegetation spatial covariation. Geophys. Res. Lett. 44, 4134–4142.

Laurance, W.F., 2004. Forest-climate interactions in fragmented tropical landscapes. Philos. Trans. R. Soc. B Biol. Sci. 359, 345–352.

Le Maitre, D.C., Scott, D.F., Colvin, C., 1999. A review of information on interactions between vegetation and groundwater. Water SA 25, 137–152.

Lean, J., Rowntree, P.R., 1999. Correction note on “Understanding the sensitivity of a GCM simulation of Amazonian deforestation to the specification of vegetation and soil characteristics.” J. Clim. 12, 1549–1551.

Lemos, H.L., Pinto, J.R.R., Mews, H.A., Lenza, E., 2013. Structure and floristic relationships between Cerrado sensu stricto sites on two types of substrate in northern. Biota Neotrop. 13, 121–132.

Lentini, M., Veríssimo, A., Pereira, D., 2005. The Expansion of Logging in the Brazilian Amazon. State Amaz. 1–4.

Lentz, D.L. (2000). Imperfect Balance: Landscape Transformations in the Pre-Columbian Americas. Columbia University Press, 788 p.

Lima, R.A.F., Rando, J.G., Barreto, K.D., 2015. Composição e diversidade no cerrado do leste de de Mato Grosso do Sul, Brasil. Rev. Árvore 39, 9–24.

Lloyd, K.K.M., McQueen, A. a. M.A., Lee, B.J., Wilson, R.C.B., Walker, S., Wilson, J.B., 2000. Evidence on ecotone concepts from switch, environmental and anthropogenic ecotones. J. Veg. Sci. 11, 903–910.

Longman, K.A. and Jeník, J. 1992. Forest-savanna boundaries: general considerations. P.A. Furley, J. Proctor, J.A. Ratter (Eds.). Nature and dynamics of forest-savanna boundaries, Chapman & Hall, London (1992), pp. 3-20

Lopes, A.S., Cox, F.R., 1977. Cerrado vegetation in Brazil: an edaphic gradient. Agron. J. 69, 828–831.

Lorenzi, H. 2002. Árvores Brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil. Instituto Plantarum, Nova Odessa, v.2, 368p.

Lorenzo, J.S., Griffith, J.J., Juchsch, I., Souza, A.L., Reis, M.G.F. & Vale, A.B.A. 1994. Fitossociologia para recuperar área de lavra. Ambiente 8(1):26-33.

Loss, A., Pereira, M.G., Perin, A., Anjos, L.H.C., 2012. Carbon and Nitrogen Content and Stock in No-Tillage and Crop-livestock Integration Systems in the Cerrado of Goias State, Brazil. J. Agric. Sci. 4, 96–105.

Lousada, E.O., Elói, J., Campos, G., 2005. Proposta de modelos hidrogeológicos conceituais aplicados aos aqüíferos da região do Distrito Federal. Terra 35, 407–414.

Lowrance, R., Sheridan, J.M., 2005. Surface runoff water quality in a managed three zone riparian buffer. J. Environ. Qual. 34, 1851–1859.

Lowrance, R., Todd, R., Fail Jr., J., Hendrickson Jr., O., Leonard, R., Asmussen, L., 1984. Riparian forests as nutrient filters.

Lowry, C.S., Loheide, S.P., Moore, C.E., Lundquist, J.D., 2011. Groundwater controls on vegetation composition and patterning in mountain meadows. Water Resour. Res. 47, 1–16.

Magurran, A.E., 2004. Measuring Biological Diversity 256.

Magurran, A.E., Dornelas, M., 2010. Biological diversity in a changing world. Philos. Trans. R. Soc. B Biol. Sci. 365, 3593–3597.

Margalef, R. 1972. Homage to Evelyn Hutchinson, or why is there an upper limit to diversity. *Transactions of the Connecticut Academy of Arts and Sciences, 44*, 211-235.

Maricato, H.S., Guilherme, F.A.G., Pereira, F.C., Carrijo, D., 2008. Fitossociologia em Campo de Murundu antropizado no município de Jataí, GO.

Marimon, B.S., Colli, G.R., Marimon-Júnior, B.H., Mews, H.A., Eisenlohr, P.V., Feldpausch, T.R., Phillips, O.L., 2015. Ecology of Floodplain Campos de Murundus Savanna in Southern Amazonia. Int. J. Plant Sci. 176, 000–000.

Marimon, B.S., Felfili, J.M., Lima, E.S., 2002. Floristics and Phytosociology of the Gallery Forest of the Bacaba Stream, Nova Xavantina, Mato Grosso, Brazil. Edinburgh J. Bot. 59, 303–318.

Marimon, B.S., Marimon-Junior, B.H., Mews, H.A., Jancoski, H.S., Franczak, D.D., Lima, H.S., Lenza, E., Rossete, A.N., Moresco, M.C., 2012. Florística dos campos de murundus do Pantanal do Araguaia, Mato Grosso, Brasil. Acta Bot. Brasilica 26, 181–196. doi:10.1590/S0102-33062012000100018

Markewitz, D., Resende, J.C.F., Parron, L., Bustamante, M., Klink, C.A., Figueiredo, R. de O., Davidson, E.A., 2006. Dissolved rainfall inputs and streamwater outputs in an undisturbed watershed on highly weathered soils in the Brazilian Cerrado. Hydrol. Process. 20, 2615–2639.

Marques, J.J., Schulze, D.G., Curi, N., Mertzman, S.A., 2004. Trace element geochemistry in Brazilian Cerrado soils 121, 31–43.

Martinelli, L. a., Naylor, R., Vitousek, P.M., Moutinho, P., 2010. Agriculture in Brazil: Impacts, costs, and opportunities for a sustainable future. Curr. Opin. Environ. Sustain. 2, 431–438.

MacDonald, G. M. 2003. *Biogeography: Space, Time, and Life*. New York, NY: John Wiley & Sons, Inc.

Medeiros, J. de D., 2006. Branched root hairs in Miconia albicans (sw.) Triana (Melastomataceae); Pelos radiculares ramificados em Miconia albicans (sw.) Triana (Melastomataceae). Insula 35, 85–94.

Mendonça, R.C., Felfili, J.M., Walter, B.M.., Silva Junior, M.C., Rezende, a. V., Filgueiras, T.S., Nogueira, P.., 1998. Flora vascular do bioma Cerrado. Cerrado Ambient. e Flora. Embrapa, Planaltina p.289-556.

Mendonça, R.C. de, Felfili, J.M., Walter, B.M., Silva Júnior, M.C. da, Rezende, A.V., Filgueiras, T. de S., Nogueira, P.E., Fagg, C.W., 2008. Flora Vascular do Bioma Cerrado, Checklist com 12356 espécies. Cerrado Ecol. e flora.

Mingoti, R., Aparecido, C., Augusto, D., Moraes, D.C., 2016. Suscetibilidade à contaminação da água subterrânea em função de propriedades dos solos no Cerrado brasileiro Groundwater contamination susceptibility as a function 1252–1260.

Morais, R.F., Morais, F.F., Lima, J.F. de, 2014. Composição e estrutura da comunidade arbórea e arbustiva em murundus no Pantanal de Poconé, Mato Grosso. Rev. Árvore 38, 443–451.

Munhoz, C.B.R., Felfili, J.M., 2007. Florística do estrato herbáceo-subarbustivo de um campo limpo úmido em Brasília, Brasil. Biota Neotrop. 7, 205–215.

Murcia, C., 1995. Edge effects in fragmented forests: implications for conservation. Trends Ecol. Evol. 10, 58–62.

Murphy, B.P., Bowman, D.M.J.S., 2012. What controls the distribution of tropical forest and savanna? Ecol. Lett. 15, 748–758.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858.

Nagendra, H., 2002. Opposite trends in response for the Shannon and Simpson indices of landscape diversity. Appl. Geogr. 22, 175–186.

Naiman, R.J., Decamps, H., 1997. The ecology of interfases: Riparian Zones. Annu. Rev. Ecol. Evol. Syst. 28, 621–658.

Naiman, R.J., Decamps, H., Pollock, M., 1993. The Role of Riparian Corridors in Maintaining Regional Biodiversity.

Naiman R.J., De´camps H (eds). 1990. The Ecology and Management of Aquatic-Terrestrial Ecotones. Man and the Biosphere Series 4, Unesco, Paris. The Parthenon Publishing Group: Carnforth, UK.

Nebel, G., 2000. Minquartia guianensisAubl.: Uso, ecología y manejo en forestería y agroforestería. Folia Amaz. 10; 201–223.

Neri, A. V., Schaefer, C.E.G.R., Silva, A.F., Souza, A.L., Ferreira-Junior, W.G., Meira-Neto, J.A.A., 2012. The influence of soils on the floristic composition and community structure of an area of Brazilian Cerrado vegetation. Edinburgh J. Bot. 69, 1–27.

Neto, M.D. de A.P.A.F.M.H. and C.E.J., 1989. The Murundus of the Cerrado Region of Central Brazil Author (s): M . Diniz de Araujo Neto , P . A . Furley , M . Haridasan , C . E . Johnson Published by : Cambridge University Press Stable URL : http://www.jstor.org/stable/2559769 2, 17–35.

Nikonov, V., Goryainova, V., Lukina, N., 2001. Ni and Cu migration and accumulation in forest ecosystems on the Kola Peninsula 42, 93–100.

Nóbrega, R.L.B., Guzha, A.C., Torres, G.N., Kovacs, K., Lamparter, G., Amorim, R.S.S., Couto, E., Gerold, G., 2017. Effects of conversion of native cerrado vegetation to pasture on soil hydro-physical properties, evapotranspiration and streamflow on the Amazonian agricultural frontier. PLoS One 12, 1–22.

Nogueira, E.N., Dores, E.F.G.C., Pinto, A.A., Amorim, R.S.S., Ribeiro, M.L., Lourencetti, C., 2012. Currently used pesticides in water matrices in central-western Brazil. J. Braz. Chem. Soc. 23, 1476–1487.

Oksanen, J., 2017. Vegan: an introduction to ordination 1, 1–10. doi:intro-vegan.Rnw 1260 2010-08-17 12:11:04Z jarioksa processed with vegan 1.17-6 in R version 2.12.1 (2010-12-16) on January 10, 2011.

Oliveira-Filho, A.T., Ratter, J.A., 1995. A Study of the Origin of Central Brazilian Forests by the analysis of plant species distribution patterns. Edinburgh J. Bot. 52, 141–194.

Oliveira-filho, A.T.D.E., 1992. Floodplain murundus of Central Brazil : evidence for the termite-origin hypothesis. J. Trop. Ecol. 8, 1–19.

Oliveira-Filho, A.T. de, Shepherd, G.J., Martins, F.R., Stubblebine, W.H., 1989. Environmental factors affecting physiognomic and floristic variation in an area of cerrado in central Brazil. J. Trop. Ecol. 5, 413–431.

Oliveira-Filho, A.T. De, Shepherd, G.J., Martins, F.R., Stubblebine, W.H., 1989. Environmental factors affecting physiognomic and floristic variation in an area of cerrado in central Brazil. J. Trop. Ecol. 5, 413.

Oliveira- Filho, A., Fontes, M., 2000. Patterns of Floristic Differentiation among Atlantic Forests in Southeastern Brazil and the Influence of Climate. Biotropica 32, 793–810.

Oliveira-Filho, A.T. and Ratter, J.A. (2002) Vegetation physiognomies and wood flora of the Cerrado biome. In: Oliveira, P.S. and Marquis, R.J., Eds., The Cerrados of Brazil: Ecology and Natural History of a Neotropical Savanna, Columbia University, New York, 91-120.

Oliveira, A.M., Silva, C.B., Ramos, W.M., Alves, F.M., Damasceno Júnior, G. a, Lopes, F.S., 2008. Vegetação herbácea e sub-arbustiva em fragmentos deCerrado na APA do Guariroba, uma área de preservação ambiental. Rev. Bras. Agroecol. 3, 87–90.

Oliveira, P.T.S., Leite, M.B., Mattos, T., Nearing, M.A., Scott, R.L., de Oliveira Xavier, R., da Silva Matos, D.M., Wendland, E., 2016a. Groundwater recharge decrease with increased vegetation density in the Brazilian cerrado. Ecohydrology.

Oliveira, P.T.S., Leite, M.B., Mattos, T., Nearing, M.A., Scott, R.L., Xavier, R.O., Maria, D., Matos, S., Wendland, E., 2016b. Groundwater recharge decrease with increased vegetation density in the Brazilian cerrado. Ecohydrology.

Oliveira, P.T.S., Nearing, M.A., Moran, M.S., Goodrich, D.C., Wendland, E., Gupta, H. V., 2014. Water Resources Research 7100–7114.

Oliveira, P.T.S., Nearing, M.A., Wendland, E., 2015. Orders of magnitude increase in soil erosion associated with land use change from native to cultivated vegetation in a Brazilian savannah environment. Earth Surf. Process. Landforms 40, 1524–1532.

Oliveira, P.T.S., Wendland, E., Nearing, M.A., Scott, R.L., Rosolem, R., Da Rocha, H.R., 2015. The water balance components of undisturbed tropical woodlands in the Brazilian cerrado. Hydrol. Earth Syst. Sci. 19, 2899–2910.

Osborne, L.L., Kovacic, D.A., 1995. Riparian vegetated buffer strips in water-quality restoration and stream management. Biol. Conserv. 71, 215.

Parron, L.M., Bustamante, M.M.C., Markewitz, D., 2011. Fluxes of nitrogen and phosphorus in a gallery forest in the Cerrado of central Brazil. Biogeochemistry 105, 89–104.

Pena-Claros, M., Poorter, L., Alarcon, A., Blate, G., Choque, U., Fredericksen, T.S., Justiniano, M.J., Leao, C., Licona, J.C., Pariona, W., Putz, F.E., Quevedo, L., Toledo, M., 2012. Soil Effects on Forest Structure and Diversity in a Moist and a Dry Tropical Forest. Biotropica 44, 276–283.

Pereira, A.C., Oliveira, S.L.J., Pereira, J.M.C., Turkman, M.A.A., 2014. Modelling fire frequency in a Cerrado savanna protected area. PLoS One 9.

Pereira, I.M., Jerônimo, G.C., Fonseca, K.R., Coneglian, A., 2015. Floristic and Phytosociological Study of Gallery Forest in Cerrado. Rev. Agrotecnologia - Agrotec 6, 1–19.

Pereira, P., Martha, G.B., Santana, C.A., Alves, E., 2012. The development of Brazilian agriculture: future technological challenges and opportunities. Agric. Food Secur. 1, 4.

Philip, M. S. 1994. Measuring trees and forests. Department of Forestry, University of Aberdeen, Aberdeen, UK. 324 pp.

Pinto, J.R.R., Lenza, E., Pinto, A.D.S., 2009. Composição florística e estrutura da vegetação arbustivo-arbórea em um cerrado rupestre, Cocalzinho de Goiás, Goiás. Rev. Bras. Botânica 32, 1–10.

Pinto, J.R.R., Mews, H.A., Jancoski, H.S., Marimon, B.S., Bomfim, B.D.O., 2014. Woody vegetation dynamics in a floodplain campo de murundus in central Brazil. Acta Bot. Brasilica 28, 519–526.

Pinto, L.V.A., Davide, A.C., Botelho, A.S., Oliveira-Filho, A.T. & Machado, E.L.M. 2005. Distribuição das espécies arbóreoarbustivas ao longo do gradiente de umidade do solo de nascentes pontuais da Bacia Hidrográfica do Ribeirão Santa Cruz, Lavras, MG. Cerne 11: 294-305.

Polcher, J., 1995. Sensitivity of Tropical Convection to Land Surface Processes. J. Atmos.

Sci.

Polyakov, V., Fares, A., Ryder, M.H., 2005. Precision riparian buffers for the control of nonpoint source pollutant loading into surface water: A review. Environ. Rev. 13, 129–144.

Ponce, V.M., Cunha, C.N. da, 1993. Vegetated Earthmounds in Tropical Savannas of Central Brazil: A Synthesis: With Special Reference to the Pantanal do Mato Grosso. J. Biogeogr. 20, 219–225.

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Raaimakers, D., Lambers, H., 1996. Response to Phosphorous of Tropical Tree Seedlings: A Comparison between Pioneer Species Tapirira obtusa and a Climax Species Lecythis corrugata.

Ratter, J.A.; Bridgewater, S.; Atkinson, R. & Ribeiro, J.F. 1996. Analysis of the floristic composition of the brazilian cerrado vegetation II: Comparison of the woody vegetation of 98 areas. Edinburgh Journal of Botany. 53 (2): 153-180.

Ratter, J.A., Richards, P.W., Argent, G., Gifford, D.R., 1973. Observations on the vegetation of northeastern Mato Grosso: I - The woody vegetation types of the Xavantina-Cachimbo expedition area. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 266, 449–489.

Ratter, J. a., Bridgewater, S., Ribeiro, J.F., 2003. Analysis of the Floristic Composition of the Brazilian Cerrado Vegetation Iii: Comparison of the Woody Vegetation of 376 Areas. Edinburgh J. Bot. 60, 57–109.

Ratter, J. a., Ribeiro, J.F., S., B., 1997. The Brazilian Cerrado Vegetation and Threats to its Biodiversity. Ann. Bot. 80, 223–230.

Ravi, S., D’Odorico, P., Okin, G.S., 2007. Hydrologic and aeolian controls on vegetation patterns in arid landscapes. Geophys. Res. Lett. 34, 1–5.

Rawitscher, F., 1948. The Water Economy of the Vegetation of the Campos Cerrados in Southern Brazil. J. Ecol. 36, 237–268.

Resende, I.L.D.M., Araújo, G.M. De, Oliveira, A.P.D.A., Oliveira, A.P. De, Ávila Júnior, R.S. De, 2004. A comunidade vegetal e as características abióticas de um campo de murundu em Uberlândia, MG. Acta Bot. Brasilica 18, 9–17.

Reys, P., Gabriela, M., Camargo, G. De, Grombone-guaratini, M.T., Teixeira, A.D.P., Antonio, M., Patricia, L., Morellato, C., 2013. Estrutura e composição florística de um Cerrado sensu stricto e sua importância para propostas de restauração ecológica 40, 449–464.

Rheinhardt, R.D., Brinson, M.M., Meyer, G.F., Miller, K.H., 2012. Carbon storage of headwater riparian zones in an agricultural landscape. Carbon Balance Manag. 7, 4.

Rhymes, J., Wallace, H., Fenner, N., Jones, L., 2014. Evidence for sensitivity of dune wetlands to groundwater nutrients. Sci. Total Environ. 490, 106–113.

Ribeiro, J. F., and B. M. T. Walter. 2001. As matas de galeria no contexto do bioma cerrado. Pages 29–47 in J. F. Ribeiro, C. E. L. Fonseca, and J. C. Sousa-Silva, editors. Cerrado: Caracterizacão e Recuperacão de Matas de Galerias. Embrapa, Planaltina, DF, Brazil.

Ribeiro, J.F., Walter, B.M.T., 2008. As principais fitofisionomias do bioma Cerrado. Cerrado

Ecol. e flora.

Ribeiro, W.C., 2008. A qüífero Guarani : gestão compartilhada e soberania 22, 227–238.

Richards, P., Pellegrina, H., VanWey, L., Spera, S., 2015. Soybean development the impact of a decade of agricultural change on urban and economic growth in Mato Grosso, Brazil. PLoS One 10, 1–18.

Richards, P.D., VanWey, L., 2015a. Farm-scale distribution of deforestation and remaining forest cover in Mato Grosso. Nat. Clim. Chang. 6, 418–425.

Richards, P.D., VanWey, L., 2015b. Farm-scale distribution of deforestation and remaining forest cover in Mato Grosso. Nat. Clim. Chang. 6, 418–425.

Rocha, A.A., Monteiro, S.H., Andrade, G.C.R.M., Vilca, F.Z., Tornisielo, V.L., 2015. Monitoring of Pesticide Residues in Surface and Subsurface Waters, Sediments, and Fish in Center-Pivot Irrigation Areas 26, 2269–2278.

Rodrigo, D.M., Pollard, A.G., 1962. Chemistry of waterlogged soils. J. Sci. Food Agric. 13, 43–48.

Rodrigues, P.M.S., Schaefer, C.E.G.R., Silva, J. de O., Ferreira Júnior, W.G., dos Santos, R.M., Neri, A.V., 2016. The influence of soil on vegetation structure and plant diversity in different tropical savannic and forest habitats. J. Plant Ecol. rtw135.

Rodrigues, T.R., Vourlitis, G.L., Lobo, F.D.A., Oliveira, R.G. De, Nogueira, J.D.S., 2014. Seasonal variation in energy balance and canopy conductance for a tropical savanna ecosystem of south central 119, 1–13.

Romero-Saltos, H., Sternberg, L.D.S.L., Moreira, M.Z., Nepstad, D.C., 2005. Rainfall exclusion in an eastern Amazonian forest alters soil water movement and depth of water uptake. Am. J. Bot. 92, 443–455.

Rosolen, V., De-Campos, A.B., Govone, J.S., Rocha, C., 2015. Contamination of wetland soils and floodplain sediments from agricultural activities in the Cerrado Biome (State of Minas Gerais, Brazil). Catena 128, 203–210.

Rossatto, D.R., de Carvalho Ramos Silva, L., Villalobos-Vega, R., Sternberg, L.D.S.L., Franco, A.C., 2012. Depth of water uptake in woody plants relates to groundwater level and vegetation structure along a topographic gradient in a neotropical savanna. Environ. Exp. Bot. 77, 259–266.

Rossatto, D.R., Hoffmann, W.A., Franco, A.C., 2009. Differences in growth patterns between co-occurring forest and savanna trees affect the forest-savanna boundary. Funct. Ecol. 23, 689–698.

Rossatto, D.R., Silva, L.C.R., Sternberg, L.S.L., Franco, A.C., 2014. South African Journal of Botany Do woody and herbaceous species compete for soil water across topographic gradients ? Evidence for niche partitioning in a Neotropical savanna. South African J. Bot. 91, 14–18.

Ruggiero, P.G.C., Pivello, V.R., Sparovek, G., Teramoto, E., Pires Neto, A.G., 2006. Relação entre solo, vegetação e topografia em área de cerrado (Parque Estadual de Vassununga, SP): como se expressa em mapeamentos? Acta Bot. Brasilica 20, 383–394.

Salemi, L.F., Groppo, J.D., Trevisan, R., de Moraes, J.M., de Barros Ferraz, S.F., Villani, J.P., Duarte-Neto, P.J., Martinelli, L.A., 2013. Land-use change in the Atlantic rainforest region: Consequences for the hydrology of small catchments. J. Hydrol. 499, 100–109.

Saporetti Jr, A.W., Meira Neto, J.A.A., Almado, R.D.P., 2003. Fitossociologia de cerrado sensu stricto no município de Abaeté-MG. Rev. Árvore 27, 413–419.

Sartor, M.B.L.B. (1994). Fenologia e biologia floral de *Miconia albicans* (Sw.) Triana e *Tibouchina stenocarpa* (DC.) Cogn. (Melastomataceae). Master's Dissertation, Universidade Estadual Paulista, Botucatu.

Schenk, H.J., Jackson, R.B., 2005. Mapping the global distribution of deep roots in relation to climate and soil characteristics. Geoderma 126, 129–140.

Schenk, H.J., Jackson, R.B., 2002. Rooting depths , lateral root spreads and below-ground / above-ground allometries of plants in water-limited 480–494.

Schleuning, M., Farwig, N., Peters, M.K., Bergsdorf, T., Bleher, B., Brandl, R., Dalitz, H., Fischer, G., Freund, W., Gikungu, M.W., Hagen, M., Garcia, F.H., Kagezi, G.H., Kaib, M., Kraemer, M., Lung, T., Naumann, C.M., Schaab, G., Templin, M., Uster, D., W??gele, J.W., B??hning-Gaese, K., 2011. Forest fragmentation and selective logging have inconsistent effects on multiple animal-mediated ecosystem processes in a tropical forest. PLoS One 6.

Scholz, F.G., Bucci, S.J., Goldstein, G., Meinzer, F.C., Franco, A.C., 2002. Hydraulic redistribution of soil water by neotropical savanna trees. Tree Physiol. 22, 603–612.

Scholz, F.G., Bucci, S.J., Goldstein, G., Meinzer, F.C., Franco, C., Salazar, A., 2008. Plant- and stand-level variation in biophysical and physiological traits along tree density gradients in the Cerrado 20, 217–232.

Shannon, C.E., 1948. A Mathematical Theory of Communication. Bell Syst. Tech. J. 27, 379–423.

Shapiro, S.S., Wilk, M.B., 1965. An Analysis of Variance Test for Normality (Complete Samples). Biometrika 52, 591.

Silva-Júnior, M.C. Da, 2005. Fitossociologia e Estrutura Diamétrica na Mata de Galeria do Pitoco, na Reserva Ecológica do IBGE, DF. Cerne 11, 147–158.

Silva, J.S.O., Bustamante, M.M. da C., Markewitz, D., Krusche, A.V., Ferreira, L.G., 2011. Effects of land cover on chemical characteristics of streams in the Cerrado region of Brazil. Biogeochemistry 105, 75–88.

Silva, J.S.O., Bustamante, M.M. da C., Markewitz, D., Krusche, A.V., Ferreira, L.G., 2010. Effects of land cover on chemical characteristics of streams in the Cerrado region of Brazil. Biogeochemistry.

Silva, L.C.R., Sternberg, L., Haridasan, M., Hoffmann, W.A., Miralles-Wilhelm, F., Franco, A.C., 2008. Expansion of gallery forests into central Brazilian savannas. Glob. Chang. Biol. 14, 2108–2118.

Silva, L.O., Costa, D.A., Espírito Santo Filho, K. Do, Ferreira, H.D., Brandão, D., 2002. Levantamento florístico e fitossociológico em duas áreas de cerrado sensu stricto no Parque Estadual da Serra de Caldas Novas, Goiás. Acta Bot. Brasilica 16, 43–53.

Simpson, E.H., 1949. Measurement of Diversity. Nature.

Skorupa, A.L.A., Fay, M., Zinn, Y.L., Scheuber, M., 2013. Assessing hydric soils in a gallery forest in the Brazilian Cerrado. Soil Use Manag. 29, 119–129.

Soares, J.V., Carriello, F., Ferreira, N.J., Rennó, C.D., 2006. A tecnologia de remoção de fósforo: Gerenciamento do elemento em resíduos industriais. Rev. Ambient. e Agua 9, 445–458.

Soltis, D.E., Soltis, P.S., Morgan, D.R., Swensen, S.M., Mullin, B.C., Dowd, J.M., Martin, P.G., 1995. Chloroplast gene sequence data suggest a single origin of the predisposition for symbiotic nitrogen fixation in angiosperms. Proc. Natl. Acad. Sci. U. S. A. 92, 2647–2651.

Spera, S.A., Galford, G.L., Coe, M.T., 2016. Land-use change affects water recycling in Brazil ' s last agricultural frontier 3405–3413.

Spera, S.A., Galford, G.L., Coe, M.T., Macedo, M.N., Mustard, J.F., 2016. Land-use change affects water recycling in Brazil's last agricultural frontier. Glob. Chang. Biol. 22, 3405–3413.

Staver, A.C., Bond, W.J., 2014. Is there a "browse trap"? Dynamics of herbivore impacts on trees and grasses in an African savanna. J. Ecol. 102, 595–602.

Sternberg, L.D.S.L., Bucci, S., Franco, A., Goldstein, G., Hoffman, W.A., Meinzer, F.C., Moreira, M.Z., Scholz, F., 2005. Long range lateral root activity by neo-tropical savanna trees. Plant Soil 270, 169–178.

Strassburg, B.B.N., Brooks, T., Feltran-barbieri, R., Iribarrem, A., Crouzeilles, R., Loyola, R., Latawiec, A.E., Filho, F.J.B.O., Scaramuzza, C.A.D.M., Scarano, F.R., Soares-filho, B., Balmford, A., 2017. Moment of truth for the Cerrado hotspot 99, 13–15.

Strassburg, B.B.N., Brooks, T., Feltran-Barbieri, R., Iribarrem, A., Crouzeilles, R., Loyola, R., Latawiec, A.E., Oliveira Filho, F.J.B., Scaramuzza, C.A. de M., Scarano, F.R., Soares-Filho, B., Balmford, A., 2017. Moment of truth for the Cerrado hotspot. Nat. Ecol. Evol. 1, 99.

Tabacchi, E., Lambs, L., Guilloy, H., Planty-Tabacchi, A.-M., Muller, E., Décamps, H., 2000. Impacts of riparian vegetation on hydrological processes. Hydrol. Process. 14, 2959–2976.

Tinker, P.B., Nye, P.H., 2000. Solute movement in the rhizosphere. Oxford University Press., Oxford.

Toribio, M., Romanyà, J., 2006. Leaching of heavy metals (Cu, Ni and Zn) and organic matter after sewage sludge application to Mediterranean forest soils. Sci. Total Environ. 363, 11–21.

Uhl, C., Clark, K., Clark, H., Murphy, P., 1981. Early Plant Succession after Cutting and Burning in the Upper Rio Negro Region of the Amazon Basin. J. Ecol. 69, 631–649.

Verstraeten, G., Poesen, J., Gillijns, K., Govers, G., 2006. The use of riparian vegetated filter strips to reduce river sediment loads: An overestimated control measure? Hydrol. Process. 20, 4259–4267.

Villalobos-vega, R., 2010. Water Table and Nutrient Dynamics in Neotropical Savannas and Wetland Ecosystems.

Villalobos-Vega, R., Salazar, A., Miralles-Wilhelm, F., Haridasan, M., Franco, A.C., Goldstein, G., 2014a. Do groundwater dynamics drive spatial patterns of tree density and diversity in Neotropical savannas? J. Veg. Sci. 25, 1465–1473.

Villalobos-Vega, R., Salazar, A., Miralles-Wilhelm, F., Haridasan, M., Franco, A.C., Goldstein, G., 2014b. Do groundwater dynamics drive spatial patterns of tree density and diversity in Neotropical savannas? J. Veg. Sci. 25, 1465–1473.

Wantzen, K.M., 2003. Cerrado streams - characteristics of a threatened freshwater ecosystem type on the Tertiary Shields of Central South America.

Wantzen, K.M., Couto, E.G., Mund, E.E., Amorim, R.S.S., Siqueira, A., Tielbörger, K., Seifan, M., 2012. Soil carbon stocks in stream-valley-ecosystems in the Brazilian Cerrado agroscape. Agric. Ecosyst. Environ. 151, 70–79.

Weigelhofer, G., Fuchsberger, J., Teufl, B., Welti, N., Hein, T., 2012. Effects of Riparian Forest Buffers on In-Stream Nutrient Retention in Agricultural Catchments. J. Environ. Qual. 41, 373.

Weisberg, P.J., Mortenson, S.G., Dilts, T.E., 2013. Gallery Forest or Herbaceous Wetland? The Need for??Multi-Target Perspectives in Riparian Restoration Planning. Restor. Ecol. 21, 12–16.

Whittaker, R.H., 1972. Evolution and Measurement of Species Diversity Author (s): R . H . Whittaker Reviewed work (s): Published by : International Association for Plant Taxonomy (IAPT) Stable URL : http://www.jstor.org/stable/1218190 . extend access to Taxon . EVOLUTION. Taxon 21, 213–251.

Wuana, R.A., Okieimen, F.E., 2011a. Heavy Metals in Contaminated Soils : A Review of Sources , Chemistry , Risks and Best Available Strategies for Remediation 2011.

Wuana, R.A., Okieimen, F.E., 2011b. Heavy Metals in Contaminated Soils : A Review of Sources , Chemistry , Risks and Best Available Strategies for Remediation. Int. Sch. Res. Netw.

Yang, W.H., Liptzin, D., 2015. High potential for iron reduction in upland soils. Ecology 96, 2015–2020.

Yruela, I., 2005. Copper in plants. Brazilian J. Plant Physiol. 17, 145–156.

Zaharescu, D.G., Palanca-Soler, A., Hooda, P.S., Tanase, C., Burghelea, C.I., Lester, R.N., 2017. Riparian vegetation in the alpine connectome: Terrestrial-aquatic and terrestrial-terrestrial interactions. Sci. Total Environ. 601–602, 247–259.

Zhang, H., McGuffie, K., Henderson-Sellers, A., 1996. Impacts of tropical deforestation. Part II: The role of large-scale dynamics. J. Clim.

Zhou, H., Li, W., 2010. Response of plant species diversity to groundwater in oasis-desert zone of the lower Tarim River, Northwest China. 2010 Int. Conf. Multimed. Technol. ICMT 2010 3–9.

Zhu, J., Yu, J., Wang, P., Zhang, Y., Yu, Q., 2012. Interpreting the groundwater attributes influencing the distribution patterns of groundwater-dependent vegetation in northwestern China. Ecohydrology 5, 628–636.

Appendices

Appendix A

Chapter 4.1

Table A.1 Plants species distributed per plot in the *campo de murundus* (N = total amount).

Species	5	6	7	8	18	17	16	15	14	N
Alchornea glandulosa	1	3	1							5
Alchornea schomburgkii		3	1	5						9
Alibertia edulis			1	3	1			1		6
Aspidosperma macrocarpum						1				1
Banisteriopsis sp					1	1				2
Bocageopsis mattogrossensis						2				2
Bowdichia virgilioides			1							1
Byrsonima clausseniana	1	2	6	3	2	6	1	8	4	33
Byrsonima laxiflora	2								2	4
Byrsonima pachyphylla						9	1			6
Casearia arborea					1	4	1	2		8
Cibianthus detergens						3				3
Connarus perrotettii						1				1
Connarus suberosus						2	2	1		5
Davilla elliptica					2					2
Dead individuals	4	4	5	4	36	12	19	7	2	93
Diplopterys lucida		1	1							2
Emotum nitens		1		1	7	2				11
Eriotheca gracilipes						4			1	5
Erythroxilum egleri						5				5
Eugenia chrysantha						2				2
Guatteria schytophyla			2							2
Heteropteris nitida							1			1
Heteropterys byrsonimifolia						3	1	4		8
Hyrthella glandulosa						1				1
Ilex sp							1			1
Kielmeyera coriacea					1	1		1		3
Lacistema aggregatum						1				1
Macairea pachyphylla	1		2	1						4
Maprounea guianensis	3	7	7		7	7	8	4	3	46
Miconia albicans		1	6	2	4	2	2	3	1	21
Miconia cuspidata	5	3	3	1		2	1			15
Miconia ferruginata						1				1
Myrcia guianensis					1	1				2
Myrcia splendens		1	1			2		2		7
Myrsine coriacea			2							2
Myrtaceae						7	1			8

Nectandra cuspidata		2			2		1	1		6
Nectandra hiypoleuca										1
Ocotea velloziana						1		1		3
Onychopetalum amazonicum						2	1	1		4
Ouratea hexasperma						5		4		9
Physocalymna scaberrima					1					1
Psidium sp					3	1		1		5
Pyptocarpha rotundifolia						4	2	5		11
Qualea dicothoma					2	3				5
Qualea grandiflora					4					4
Qualea parviflora					1					1
Rapanea guianensis						6		3		9
Roupala montana					1					1
Simarouba amara		23	1			8	2			34
Siparuna guianensis			1			2				3
Styrax ferrugineus			1					2		3
Symplocos sp	5	4								9
Tachigali vulgaris	5	3	1		7	5		1	5	27
Tapirira guianensis		2								2
Tapirira obtusa						1	7			8
Tibouchina stenocarpa		14	28	35	30	18		24	12	161
Virola sebifera			4	1						5
Vismia amazonica			1							1
Vismia augusta		1								1
Vismia guianensis				5	4	2	2	1	2	11
Vismia macrophylla			1							1
Xylopia aromatica	1		1	1	5	13	5	11	4	41
Total per plot	**28**	**75**	**78**	**62**	**123**	**153**	**59**	**88**	**36**	**706**

Appendix B

Chapter 4.1

Table A.2 Plants species distributed per plot in the *cerrado sensu stricto* (N = total amount).

Species	20	21	22	23	24	25	26	27	28	30	31	32	33	34	35	36	37	38	N
Agonandra brasiliensis							1												1
Andira cuyabensis	3			2	2	3	4	1	1			1			1	1			19
Annona crassifolia											2								2
Ardisia lhotzkiana																	1		1
Aspidosperma macrocarpum				1									2		1	1	1	1	7
Aspidosperma tomentosum			1				1												2
Bauhinia sp																		1	1
Bowdichia virgilioides	4	4		1	1						9	2	3	2			1	1	28
Brosimum gaudichaudii									1										1
Buchenavia tomentosa								1						2	1		1		5
Byrsonima arthropoda											1								1
Byrsonima basiloba							1												1
Byrsonima coccolobifolia	5	2	2	3	4	3	2	1			3	1	3		2	1	3	1	36
Byrsonima pachyphylla	4	3	3	1		1		3			16		7	7	9		3	9	66

Caryocar brasiliense		4	10	4	4	1						1	2	5	7	1			39
Connarus suberosus	1			1	3								1	2		1		1	10
Couepia grandiflora																	3		3
Cybianthus detergens	10	10	7	14	9	7	7	12	5		19	4	1	7	7	9	6	15	149
Dalbergia miscolobium									1										1
Davilla elliptica		9	9	7	11	11	12	30	22		2	4	3	13	3	4	8	15	164
Dead individuals	2	2	1	3	2	3	2				4	2	5	8	4	2	3	4	47
Dimorphandra mollis		1	3	1	3		1	4	1		1			2	1	4			22
Diospyros hispida			1	1			3	2	2					1	2	1			13
Emmotum nitens	1										4	1	3	2			2	3	16
Eremanthus mattogrossensis									1										1
Eriotheca gracilipes	4	3	5	1	2						4	1		4	1			5	35
Erythroxilum engleri		3	2	1		7			3		1					1	4	1	23
Erythroxilum suberosum															2				2
Erythroxilum tortuosum					2	1	1	1								1			6
Eugenia aurata						2											1		3
Eugenia chrysantha					1													1	2
Ficus sp						1													1
Guapira noxia								2			1	2	2		1				8
Hachornia speciosa																		1	1
Handroanthus chrysotrichus	1			5	1										1		1	3	12

Handroanthus ochraceus			1				2	1	1				1	4	1	1	2	1	15
Heteropterys byrsonimifolia				4		1								3					8
Heteropterys coriacea							1												1
Hymathantus obovatus												1							1
Hymathantus sucuubus						1									1				2
Hymenaea stignocarpa		2	1	1				3				3			1		2		13
Kielmeyera coriacea	11	9	10	10	10	8	3	3			2	5	8	11	6	6	8	15	125
Kielmeyera rubriflora				2	3														5
Kielmeyera sp							1									3	8		12
Lafoensia pacari						1		2										2	5
Leptolobium dasycarpum													2						2
Leptolobium nitens		1																	1
Licania humiles				1															1
Machaerium myrianthum														1					1
Macherium opacum						1	1									1		1	4
Maprounea guianensis																		3	3
Mauritia flexuosa										2									2
Miconia albicans		1	1						1				2		1	1	4	1	12
Miconia brevipes		1																	1
Miconia ferruginata			4	2			1								2			5	14
Mimosia humilis								1										4	5

Mouriri elliptica		3		1		3	4	2	2		1			2	1	3			22
Mouriri pusa							2		1										3
Myrcia bella						1													1
Myrcia crulsiana														1					1
Myrcia dealbata		1		2	3	11	3	15				2	1		2	17	22	11	90
Myrcia rostrata	3	7	4	6	6	21	1				9		4	6	4	3	10	2	86
Myrcia sp											1	1		1					3
Myrcia splendens											13	2	5			1		3	24
NI												1							1
Ocotea acutangula													1						1
Ocotea velloziana						1													1
Ouratea hexasperma	3	5	9	19	9	4	7	4	1		10	8	2	3	3	4	8	4	103
Piptocarpha rotundifolia	1	3	3		5	1		1	1			1	2	2		2			22
Plathymenia reticulata	1		3	1		2							1						8
Plenckia populnea	2																		2
Pouteria ramiflora				2	1	3	2	5	1						2				16
Pouteria torta				1	3	2	5	2	4					1				1	19
Psidium sp	1	2	1	2	3	2	1	1	2		3	4	7	3	1	4	3	3	43
Pterodon pubescens													1				4		5
Qualea grandiflora	4	4	2	6	15	11	7	1			9	2	9	1		2			73
Qualea multiflora						2							1	2		1	5	2	13
Qualea parviflora	4	5	11	3	11	14	1	1			3	3	4	15	13	11	8	6	113
Rapanea guianensis													1					1	2
Roupala montana	12	8	14	12	5	11	4	7	11		8	12	14	14	13	14	5	3	167
Salacia crassifolia	2				1	2	1	1							1		1		9

Schefflera macrocarpa							1												1
Schefflera malmei						1													1
Siparuna guianensis						1													1
Sthrychnos guianensis												5							5
Sthrychnos pseudochina									1										1
Stryphnodendron rotundifolium	1		2	2		1	1	1	2			1	2	2	1	1			17
Styrax ferrugineus	5		3		2	1			7		3								21
Tabebuia aurea				3	2	2			2			1	1	1	1	3			16
Tabebuia ochracea								1											1
Tachigali subvelutina							1						1	3					5
Tachigali vulgaris	9	3	4	3	2		2		2		3	3	8	4	3	5	5	5	61
Tapirira guianensis										1	1								2
Tapirira obtusa											1							1	2
Vochysia rufa	1		1	1		1	1				1					1			6
Vochysia sp											1								1
Xylopia aromatica													1	1	2			2	6
Total per plot	**95**	**96**	**118**	**130**	**126**	**150**	**88**	**109**	**76**	**3**	**136**	**74**	**111**	**140**	**102**	**111**	**133**	**138**	**1935**

Appendix C

Chapter 4.1

Table A.3 Plant species distributed by plots in the gallery forest, with the total value.

Species	1	2	3	4	9	10	11	12	13	19	29	Total
Alchornea glandulosa			2									3
Alibertia edulis				1								1
Amaioua guianensis					5	3	8					16
Apuleia leiocarpa									1			1
Aspidosperma excelsum	1											1
Aspidosperma desmanthum									1			1
Bellucia grossularioides	2	1										3
Bocageopsis mattogrossensis								1		2	2	5
Bredemeyera lucida				1								1
Buchenavia macrophylla									1			1
Byrsonima arthropoda		1										1
Byrsonima chrysophylla		1		1					1	1	4	8
Casearia arborea										1		1
Chaetocarpus echinocarpus								1			1	2
Connarus perrotettii										1	1	2
Cordia bicolor	2	1				5	2		2			12
Croton palagostina	1			1			1					3
Dacryoides microcarpa			1									1
Diospyros sericea			1									1
Dyrcia sp					1		1					1
Ecclinusa ramiflora	1						1					2
Emotum nitens									4		1	5
Enterolobium scomburkii							1					1
Ficus sp					1							1
Guatteria foliosa							1		1			2
Guatteria schytophyla			1			1						2
Handroantus impetiginosus									1			1
Himatanthus articulatus			1							2		3
Humiria balsamifera											1	1
Hydrochorea corymbosa	2											2
Inga pezizifera		2	1			3	1					7
Inga vera			3	3			1		3			10
Jacaranda copaia		1			1	1						3
Kielmeyera sp										4		4
Lamanonia ternata									1			1
Licania apetala						1						1
Licania kunthiana								1			2	3
Mabea fistulifera	1	1				3		1				6

Machaerium myrianthum	1											1
Miconia brevipes					2	2	2	1				7
Miconia egensis					1							1
Miconia cuspidata	1	6					2					9
Miconia sp					1	7	2					10
Micropholis guyanensis		2			2		1					5
Micropholis venulosa			2				1					3
Minquartia guianensis	4	4	1		1							10
Dead individuals	1	4	3	3	2		2	1	3	2		22
Myrcia amazonica							1					1
Myrcia splendens										2	2	4
Myrciaria dubia							2	2				4
Myrsine coriacea				1	1				2		1	5
Nectandra cuspidata	1				6	2		3	5			17
Nectandra hihua						1	1	1				3
Ocotea acyphella	2	3										5
Ocotea leucoxylum	1	1	1				1					4
Ocotea velloziana					1				1			2
Ormosia paraensis	1		1									2
Physocalymna scaberrima							1		1	1	2	5
Pouteria filipes			1									1
Pouteria ramiflora					1		1	1				3
Protium heptaphyllum	1		1	1						1		4
Protium pilosissimum			1					3	1			5
Protium spruceanum		1	13	3	1				1			19
Pseudolmedia laevigata		1			1	1						3
Pseudolmedia laevis	1	1			1							3
Qualea dicothoma									3			3
Quiina cruegeriana						1						1
Sacoglottis guianensis	3	1		1	1			1	1	5		13
Schefflera morototoni					2	1					1	4
Simarouba amara			1	1	1	1				1		5
Sloanea eichleri	1				3		3	1				8
Sparattosperma leucanthum							1					1
Tachigali vulgaris										2	2	4
Tapirira guianensis					1	1	1	1	1	1		6
Tapirira obtusa			4	17					6		3	30
Virola calophylla						1						1
Virola sebifera											1	1
Vismia macrophylla	2											2
Xylopia amazonica								6				6
Xylopia aromatica				1								1
Xylopia chivantinensis	1											1

Xylopia polyantha						4						4
Total Geral	**31**	**32**	**40**	**35**	**36**	**39**	**39**	**26**	**41**	**27**	**24**	**370**

Curriculum vitae

Taciana Ziembowicz

5th January 1984, São Luiz Gonzaga, Brazil

taciana.ziembowicz@geo.uni-goettingen.de

Düstere-Eichen-Weg, 70 37073 Göttingen

EDUCATION

Doctoral studies, University of Goettingen, Germany (hand-in date: February 2018) 2013-2018

Area of expertise: landscape ecology, vegetation, groundwater ecology

M.Sc. in Environmental Science and Tecnology, University of Vale do Itajaí, Brazil 2010-2012

Especialization in Environmental Education, Federal University of Paraná, Brazil 2008-2009

BSc. in Biology, University of Caxias do Sul, Brazil, 2002-2007

WORKING EXPERIENCE

Research assistant, University of Goettingen, Departament of Physical Geography 2013 - 2018

Biologist, City of Brusque Environmental Agency (Fundema), Brusque, Brazil 2012 - 2013

Research assistant, University of Vale do Itajaí, Brazil 2010 - 2012

HONORS, AWARDS AND GRANTS

PhD scolarship grant

Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, Brazil – CAPES 2013-2018

Master scholarship

Fundação de Amparo à Pesquisa e Inovação, Brazil – FAPESC 2010-2012

SELECTED TRAINNING COURSES

Advanced Geographic Information System (GIS) 2015 – 2015

Introduction Geographic Information System (GIS) 2015 - 2015

Academic Writing 2014 - 2014

SELECTED PUBLICATIONS

Book chapter:

ZIEMBOWICZ, T; LIMA, S; LIMA, J.E.S. 2011. Human Being and Environment: environmental perceptions of two different regions of Garopaba, Santa Catarina. In: José Edmilson de Souza-Lima; Sandra Mara Maciel-Lima. (Org.). Environmental perception and risk: interdisciplinary contribution. 1ed. Curitiba: CRV, p.105-128.

Peer-reviewed papers:

ZIEMBOWICZ, T.; MARENZI, R.; SPINOZA, H. 2014. Analysis of the Land Use and Cover of the coastal promontories of the North-Central of Santa Catarina State, Brazil. Geosul. v.29. p. 43-64.

ZIEMBOWICZ, T; LIMA, S; LIMA, J.E.S. 2010. Human Being and Environment: environmental perceptions of two different regions of Garopaba, Santa Catarina. Gaia Scientia (UFPB), v.3, p. 83-93.

Peer-reviewed paper (in submission or review phase – only as first author):

NÓBREGA, R. L. B. & ZIEMBOWICZ, T. (shared first authorship). Assessment of a riparian zone as an ecosystem service provider in a agroindustrial area in the Amazonian Agricultural Frontier. Target Journal: Environmental Monitoring and Assessment.

Conference papers and abstracts:

ZIEMBOWICZ, T.; OLIVEIRA, E. A.; GEROLD, Gerhard . Plant Diversity and its Hydrological Relations to Groundwater Level in the Riparian Zine of Cerrado in Mato Grosso State, Brazil. In: ECOSUMMIT 2016: Ecological Sustainability: Engineering Change, 2016, Montpellier. Annals of the ECOSUMMIT, 2016.

ZIEMBOWICZ, T.; NOBREGA, R. B. ; AMORIM, R. ; GEROLD, Gerhard . The role of the Riparian Zones as an Ecohydrological Control of the Environment Quality in the Amazonian Agricultural Frontier. In: HydroEco2015: 5th Multidisciplinary Conference on Hydrology and Ecology, 2015, Vienna. Annals of the 5th Multidisciplinary Conference on Hydrology and Ecology, 2015.