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Recognition of urban green space ecosystem services for adaptation to extreme climate events. Methodological Validation

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Authors' notes'

The authors have no conflicts of interest to declare.

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Abstract

Objective: This study evaluated the ecosystem services of water regulation (EvapoTranspiration, ET) and Forest Carbon Stock (ECF) in the urban area of Campo Grande based on mapping and random sampling stratification of diameters at breast height (DBH or simply d) per unit area in five types of Urban Green Spaces (EVU).

Methodology: The evaluation of ecosystem services for water regulation ET and ECF in the urban area of Campo Grande was based on mapping and random sampling stratification of diameters at breast height (DBH or simply d) per unit area in five EVU typologies. By integrating d data - its distribution follows a Power Law - with the ecohydrological concepts and the Ecological Metabolic Theory (EMT), the medians and interquartile ranges for ET and ECF of the identified EVU typologies were then calculated.

Originality/Relevance: Despite the importance of ecosystem services in cities, few studies show methodologies to evaluate and quantify them. The present study brings an unprecedented approach to estimate ECF and ET in EVU with typical cerrado tree vegetation. The methodology is used to prospect the impact of the increase in EVU area and its ecosystem services (ECF and ET) on Carbon (C) capture and the water and thermal regulation. Therefore, the methodology aims on the security of urban citizens from tropical regions against future scenarios of extreme (episodic) flood and wave events or (persistent) heat islands.

Results: The mapping of EVU and their respective ecosystem services in Campo Grande showed the deficiency of these environments in certain parts of the city. Currently, the EVU areas in Campo Grande sum up to 898 hectares (2.5% of the urban area in 2010), which store between 33,368.5 and 456,801.7 tons of C in the form of forest biomass and they are responsible for daily atmospheric humidification on a scale of 31,458.0 to 105,277.3 m3 of water. The study also reveals that ecosystem regulation services such as ecohydrological concepts like Forest Carbon Stock (ECF) and Evapotranspiration (ET) in the urban area can be estimated by integrating DBH data (d). The results suggest that the scaling of EVU from 2.5 to

10% of the urban area in Campo Grande may have important consequences for the adaptation of future urban generations and for the mitigation of climate change.

Theoretical/methodological contributions: Statistical analyzes show that the values obtained with the field survey can be modeled by the distributions of power law through the Ecological Metabolic Theory (TME). It was found that the TME has great application potential, but also limitations, as it allows evaluating flows and stocks in a system only for intervals (interquartiles) that contain the average of the distribution. The use of the interquartile to evaluate natural processes with a power law distribution guarantees a reliable margin of uncertainty, which can be scaled independently of the woody species and its successional stage, seasonality and environment.

Social / management contributions: The results show the importance of increasing these spaces to maximize the realization of ecosystem services for atmospheric C capture, as well as for adapting urban areas to face extreme floods, heat waves and for the prevention of urban heat islands (IUC). In addition, future studies should be conducted for the geolocation of new EVU that maximize ecosystem services, which also incorporate sociocultural aspects.

Key-words: ecohidrology, urban forest, heat islands, parks, urban planning

Reconhecimento dos Serviços Ecossistêmicos de Espaços Verdes Urbanos para a Adaptação a Eventos Climáticos Extremos. Validação Metodológica

Resumo

Objetivo: Este estudo avaliou os serviços ecossistêmicos de regulação hídrica (EvapoTranspiração, ET) e de Estoque de Carbono Florestal (ECF) na área urbana de Campo Grande com base no mapeamento e na amostragem aleatória estratificada de diâmetros à altura do peito (DAP ou simplesmente d) por unidade de área em cinco tipologias de Espaços Verdes Urbanos (EVU).

Metodologia: A avaliação de serviços ecossistêmicos de regulação hídrica ET e ECF na área urbana de Campo Grande foi feita com base no mapeamento e na amostragem aleatória estratificada de diâmetros à altura do peito por unidade de área em cinco tipologias de EVU. Integrando os dados de d, cuja distribuição segue uma Lei de Potência, aos conceitos ecohidrológicos e da Teoria Metabólica Ecológica (TME), calculou-se então as medianas e os ranges de interquartil para ET e ECF das tipologias de EVU identificadas.

Originalidade/Relevância: Apesar da importância dos serviços ecossistêmicos nas cidades, poucas pesquisas mostram metodologias para avaliá-los e quantificá-los. O presente estudo traz uma abordagem inédita para estimar ECF e ET em EVU com vegetação arbórea típica de cerrado. A metodologia é usada para se prospectar o impacto do aumento em área de EVU e de seus serviços ecossistêmicos (ECF e ET) sobre o sequestro de Carbono (C) e a regulação hídrica e térmica, isto é, sobre a segurança de cidadãos urbanos de regiões tropicais em relação a futuros cenários de eventos extremos de enchentes e de ondas (episódicas) ou ilhas (persistentes) de calor.

Resultados: O mapeamento dos EVU e dos seus respectivos serviços ecossistêmicos em Campo Grande, revelou a deficiência destes ambientes em certos setores da cidade. Atualmente, as áreas de EVU em Campo Grande totalizam 898 hectares (2,5% da área urbana em 2010), as quais estocam entre 33.368,5 e 456.801,7 toneladas de C na forma de biomassa florestal e são responsáveis pela umidificação atmosférica diária da ordem de 31.458,0 a 105.277,3 m^3 de água. O estudo também revela que os serviços ecossistêmicos de regulação, traduzidos em conceitos ecohidrológicos como Estoque de Carbono Florestal (ECF) e Evapotranspiração (ET) na área urbana, podem ser estimados integrando-se dados de DAP (d). Os resultados sugerem que o escalonamento de EVU de 2,5 para 10% da área urbana em Campo Grande pode ter reflexos importantes para a adaptação das futuras gerações urbanas e para a mitigação das mudanças climáticas.

Contribuições teóricas/metodológicas: As análises estatísticas evidenciam que os valores obtidos com o levantamento de campo podem ser modelados por distribuições de leis de potência por meio da Teoria Metabólica Ecológica (TME). Constatou-se que a TME tem grande potencial de aplicação, mas também limitações, pois permite avaliar fluxos e estoques em um sistema apenas para intervalos (interquartis) que contém a mediana da distribuição. O uso do interquartil para avaliar processos naturais com distribuição de lei de potência garante uma margem confiável de incerteza, a qual pode ser escalonada independentemente da espécie lenhosa e de seu estágio sucessional, da sazonalidade e do ambiente.

Contribuições sociais / para a gestão: Os resultados evidenciam a importância do aumento desses espaços para maximizar a realização de serviços ecossistêmicos de sequestro de C atmosférico, bem como para a adaptação de áreas urbanas para o enfrentamento de enchentes extremas, ondas de calor e para a prevenção de ilhas urbanas de calor (IUC). Além disso, estudos futuros devem ser conduzidos para a geolocalização de novos EVU que maximizar os serviços ecossistêmicos, que incorporem também os aspectos socioculturais.

Palavras-chave: ecohidrologia, floresta urbana, ilhas de calor, parques, planejamento urbano

Reconocimiento de los Servicios Ecosistémicos de los Espacios Verdes Urbanos para la Adaptación a Eventos Climáticos Extremos. Validación Metodológica

Resumén

Objetivo: Este estudio evaluó los servicios ecosistémicos de regulación hídrica (EvapoTranspiración, ET) y Stock de Carbono Forestal (ECF) en el área urbana de Campo Grande a partir de mapeo y muestreo aleatorio estratificado de diámetros a la altura del pecho (DAP o simplemente d). por unidad de superficie en cinco tipos de Espacios Verdes Urbanos (EVU).

Metodología: La evaluación de los servicios ecosistémicos de regulación hídrica ET y ECF en el área urbana de Campo Grande se realizó a partir de mapeo y muestreo aleatorio estratificado de diámetros a la altura del pecho por unidad de área en cinco tipologías de EVU. Integrando los datos d, cuya distribución sigue una Ley de Potencia, con los conceptos ecohidrológicos y la Teoría Metabólica Ecológica (TME), se calcularon las medianas y rangos intercuartílicos para ET y ECF de las tipologías EVU identificadas.

Originalidad/Relevancia: A pesar de la importancia de los servicios ecosistémicos en las ciudades, pocas investigaciones muestran metodologías para evaluarlos y cuantificarlos. El presente estudio aporta un enfoque sin precedentes para estimar el ECF y la ET en EVU con vegetación arbórea típica del cerrado. La metodología se utiliza para prospectar el impacto del aumento del área de EVU y sus servicios ecosistémicos (ECF y ET) en el secuestro de carbono (C) y la regulación hídrica y térmica, es decir, en la seguridad de los ciudadanos urbanos de las regiones tropicales en relación con Escenarios futuros de inundaciones extremas y olas (episódicas) o islas de calor (persistentes).

Resultados: El mapeo de las EVU y sus respectivos servicios ecosistémicos en Campo Grande reveló la deficiencia de estos ambientes en ciertos sectores de la ciudad. Actualmente, las áreas de EVU en Campo Grande suman 898 hectáreas (2,5% del área urbana en 2010), que almacenan entre 33.368,5 y 456.801,7 toneladas de C en forma de biomasa forestal y son responsables de la humidificación atmosférica diaria del orden de 31.458,0 a 105.277,3 m3 de agua. El estudio también revela que los servicios ecosistémicos regulatorios, traducidos en conceptos ecohidrológicos como las reservas de carbono forestal (ECF) y la evapotranspiración (ET) en áreas urbanas, pueden estimarse integrando datos DAP (d). Los resultados sugieren que escalar la EVU del 2,5 al 10% del área urbana en Campo Grande puede tener consecuencias importantes para la adaptación de las futuras generaciones urbanas y para la mitigación del cambio climático.

Aportes teóricos/metodológicos: Los análisis estadísticos muestran que los valores obtenidos del estudio de campo pueden ser modelados mediante distribuciones de leyes de potencia a través de la Teoría Metabólica Ecológica (TME). Se encontró que el TME tiene un gran potencial de aplicación, pero también limitaciones, ya que permite evaluar flujos y stocks en un sistema sólo para intervalos (intercuartiles) que contienen la mediana de la distribución. El uso del intercuartil para evaluar procesos naturales con una distribución de ley de potencia garantiza un margen de incertidumbre confiable, que puede escalarse independientemente de la especie leñosa y su etapa sucesional, estacionalidad y ambiente.

Contribuciones sociales/a la gestión: Los resultados resaltan la importancia de aumentar estos espacios para maximizar la realización de los servicios ecosistémicos de secuestro de C atmosférico, así como para la adaptación de las áreas urbanas para enfrentar inundaciones extremas, olas de calor y para la prevención del calor urbano. islas (IUC). Además, se deberían realizar futuros estudios para geolocalizar nuevas EVU que maximicen los servicios ecosistémicos, que también incorporen aspectos socioculturales.

Palabras clave: ecohidrología, bosque urbano, islas de calor, parques, planificación urbana

Introduction

Urban Green Spaces (EVU) such as parks, university campus areas, military areas, gardens, courtyards and urban forests are important producers of environmental services in cities. However, the focus of research on EVU and the services they offer has been greater in developed countries in the boreal zones, temperate zones and subtropical forests of the planet (Kabisch et al., 2015; Escobedo et al, 2010; Davies et al., 2013).

Studies on EVU and the ecosystem services provided still need to be better disseminated, particularly in countries in development (Tavares et al., 2019). For that, an interdisciplinary approach is necessary, one which brings together concepts and knowledge from the exact, social and natural sciences. Considering the sociodemographic and environmental challenges faced by cities around the world, we aim to make the urban environment more inclusive, safer, more resilient and sustainable (UN, 2018), and for that there is a need for new qualitative and quantitative scientific methods that allow subsidizing the decision-making through public policies for sustainable development in the urban environment (Niemela, 2014).

Some of the regulatory ecosystem services, such as the Forest Carbon Stock (ECF) and EvapoTranspiration (ET), can be estimated using allometric equations and the Ecological Metabolic Theory (EMT). West, Enquist and Brown (2009a) revisit their theories (West, Brown & Enquist, 1997) reiterating that the physiological and morphological characteristics of plants obey allometric scale relations, which are typically expressed by power laws $Y = Y_0 r^{\varphi}$, where Y is a dependent variable such as metabolic rate, leaf area or biomass, Y_0 is a normalization constant, φ is the allometric exponent, and r represents a linear measure such as radius r or diameter (d = 2r) of the trunk or stem. The possibility of generalization of the theory can be attributed to two interconnected physico-biological phenomena: metabolism and allometry. Limited by the fundamental laws of Thermodynamics, these phenomena determine how resources are extracted from the environment, translocated and transformed within the plant and allocated for its survival, growth and reproduction. These processes in individual woody trees propagate in scale (as scale-invariant fractal processes from micro to macro) and thus produce emergent universal properties in forests, such as structure and size, spacing relationships, and growth rates. and mortality.

The TME suggests, for example, that mortality rates may be linked to metabolic and growth rates limited by the size of individuals (West, Enquist & Brown, 2009b). Obviously, observation in nature often does not follow theoretical models ipsis litteris (Coomes & Allen, 2009; Coomes et al., 2011). For macroscopic scales equal to or greater than the scale of individuals, possible TME “deviations” may be related to adaptive variations, individual and/or collective, to local and/or regional environmental conditions (Enquist et al., 2015; Bergier et al., 2016).

Scientometric analysis of EVU using TME shows a huge gap and also a research opportunity (Tavares et al., 2021) for proposing new methodologies for quantifying ecosystem services. For example, Bergier et al. (2016) present an applied research in cordillera forests (typical of cerrado) of Nhecolândia, in the brazilian Pantanal, which provides empirical and theoretical support for the application of TME to estimate the integral biomass B (from root to leaves) of vegetation individuals woody from the stem diameter d by means of the theoretical equation $d \sim B^{3/8}$ (West, Brown & Enquist, 1997).

The use of TME to estimate the total biomass B of individuals in forests in the Cerrado, based on the radius or diameter of the trunk, is feasible since the arboreal vegetation in the studied region of the Pantanal is cerrado. Therefore, it presents a similar taxonomic composition. Furthermore, as the empirical equations generated by Bergier et al. (2016) are taxon-independent, it becomes possible to quantify in a generic way, and within a limited range of uncertainty, some of the ecosystem services in natural spaces, such as farms in the Pantanal, Cerrado or even EVU, as long as the landscape forest is characterized as cerrado. It is possible that this methodology is also applicable to other Brazilian biomes, since all woody plants must have similar strategies to deal with thermodynamic and structural constraints (NIKLAS, 1994).

Although the equations demonstrate that the woody plants in the cordillera forests of the Nhecolândia ~~mountain range~~ do not obey the theoretical 1:1 ratio between the above and below ground biomass due to the adaptations of the roots and branches to the high water table (SALIS et al., 2014; BERGIER et al., 2016), the total mass of the plant follows the theoretical allometric equation $d \sim m^{3/8}$ (West, Brown & Enquist, 1997). This suggests that the total mass of the individual follows a fractal scaling law, but each individual has phenotypic plasticity to allocate more biomass above or below ground depending on the limiting conditions of the environment in which it develops (Bergier et al., 2016). In contrast to the cerrado of Nhecolândia in the Pantanal, the same vegetation in the Cerrado biome allocates more biomass below ground (in search of groundwater) through the root system, conferring greater biomass and carbon stock below than above ground (Bustamante et al. EVu in Campo Grande, 2012).

To estimate the ECF per unit area, it is necessary to integrate the masses of individual plants present in a delimited space. The EMR indicates that the frequency distribution of d, or simply the probability P(d) follows a power law as a function of d as P(d) ~ d-2 (Enquist & Bentley, 2012). In order to verify this probability distribution function and estimate ECF it is necessary to have sample techniques of diameters per unit area (Higa et al., 2014). The same happens to estimating, for example, water regulation processes by ET based on scale relationships between d and water transport through the xylem (Enquist et al., 1998; Enquist & Bentley, 2012) which mathematically translates to ET ~ dφ.

In summary, the present study brings an unprecedented approach to estimate ECF and ET in EVU (or in any other forest spaces with tree vegetation typical of the cerrado) within an uncertainty range defined by the interquartile (range of values that comprises 50% of the data of the sampling distribution) given the non-normal distribution of d values (Enquist & Bentley, 2012). In the present study, the methodology is used to prospect the impact of the increase in area of EVU and its ecosystem services (ECF and ET) on C capture and water and thermal regulation which applies to the security of urban citizens of tropical regions in relation to future scenarios of extreme flood events and (episodic) waves or (persistent) heat islands. The issue of this study is the methodological validation of the applicatiion of the alometric equations TME from BERGIER et al (2016), to quantiify ecosystem services of cerrdo forests, in case of EVU in Campo Grande, Mato Grosso do Sul.

Material and Methods

Mapping of Urban Green Spaces (EVU)

The research is based on the register of State and Federal Units of Nature Conservation located in the urban perimeter. These registers are available by the Socioeconomic Profile of Campo Grande (PLANURB, 2017) and they addressed only public EVU with relevant vegetation intended for nature conservation - as well as other functions specific to each EVU. According to this register, EVU are divided into: Conservation Units; Parks and other Conservation Units; and Linear Parks.

The mapping of EVU is of great importance for their identification and characterization because they also make it possible to understand how they are distributed in the urban fabric. The QGIS software (QGIS, 2018) was used with a Bing satellite image obtained from the Open Layers plugin (Kalberer & Walker, 2019) to map the EVU divided into three types:

Conservation Units (UC): territorial spaces intended for the conservation of the natural heritage according to the right of an ecologically balanced environment, guaranteed to citizens by the Federal Constitution of 1988. According to the National System of Nature Conservation Units (SNUC), the UC are "territorial spaces and their environmental resources, which also include the jurisdictional waters, with relevant natural characteristics, legally instituted by the Government, with conservation objectives and defined limits, under a special administration regime" art . 1st, I (BRASIL, 2011).

Parks and Protected Areas (P): public open spaces located in strategic places in the city where they can fulfill their ecological role of protecting natural resources and processes, and which, among other functions of each one, offer the community contemplation of nature allied to recreation, leisure and culture.

Linear Parks (PL): public open spaces that aim to protect the city's water courses, maintaining the banks of streams and springs with riparian forests, reducing the negative effect of floods and serving as ecological corridors. The implantation of linear parks in Campo Grande took place since 2000, which have been presented as an important structuring element of the city's landscape; in addition to their environmental functions, they provide leisure and contemplation areas for the population.

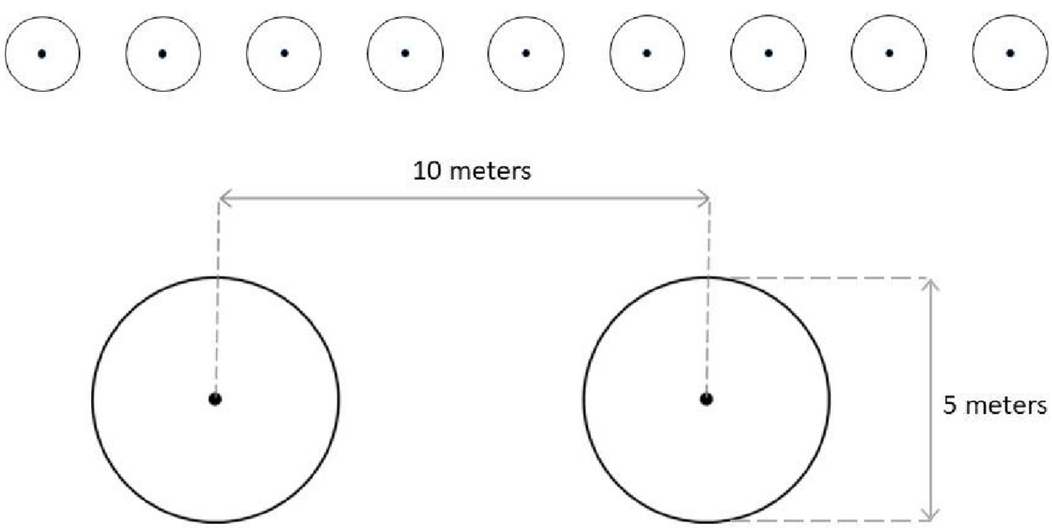
Field survey

Based on the forest sampling methodology (Higa et al., 2014) adapted for random sampling stratification (Sampath, 2001), the map of EVU typologies was used in the selection of 5 EVU to obtain data on diameters at breast height (DAP or simply d) per area unit, being two Linear Parks, two Parks and Protected Areas and one Conservation Unit. Data collection was performed for individuals with chest height d > 130 cm.

For DAPs measurements, a cluster in a straight line was stipulated for each EVU sampled, and each cluster contains ten circular plots of five meters in diameter, ten meters apart from their centers (Image 2).

Image 2

Sample of measurements and distances between plots in sampling clusters



Source: Authors

Each plot composes a sampling unit, where d values were measured for each tree and small tree present within its perimeter. The measurement took place with a measuring tape at a chest height considered to be 1.30 m (Higa et al., 2014). Each tree/plot was georeferenced and registered by photograph (geotagging via smartphone).

Field data analysis approach

1 Statistical evaluation of DAP (d)

With the Past application (Hammer et al., 2001) statistical tests by Shapiro-Wilk, Anderson-Darling and Jarque-Bera were applied to check whether or not the P(d) distribution follows a distribution for each type of UVE. Since the P(d) does not follow a normal distribution (Enquist & Bentley 2012), the non-parametric Kruskal-Wallis (KW) test was applied to compare the medians (within interquartiles) of d of EVU typologies. In the KW test, analogous to the Anova (Analysis of Variance) used in normally distributed samples, if the test result is significant (5% significance level, therefore for $p < 0.05$), then at least one type of EVU differs from the others. Dunn's nonparametric post-hoc test is analogous to Tukey's test (in parametric statistics), and allows for the verification of significant or non-pair-by-pair differences.

2 Estimation of total biomass and forest carbon stock

The total biomass (B in kg) of each woody individual was calculated from ds (diameter at ground level), where ds = 2*((√(3.1515*π*r2))0.894/π) derived from the log relationship -log between d (=2r) and ds (=2rs) (Bergier, personal communication), and the four allometric equations by Bergier et al., (2016) (see fig. 2 on page 139), whose integration over the interval 0.3 > d > 100 cm with Δd = 3 cm gives the equation B = 0.2d2.35. It’s important to notice that the empirical scale exponent obtained approaches the theoretical value 8/3 (~2.67) (West, Enquist & Brown, 2009a; Enquist & Bentley, 2012).

The ECF of each woody individual was then obtained by multiplying the value of B by 0.5 (Nowak, 1994; Nowak & Crane, 2002). 4.2.4.3. Estimation of Evapotranspiration The evapotranspiration of each woody individual (ETi,j, in mm/d) was estimated from the general empirical relationship of scale between d (cm) and the transport of water by the xylem (L/d) given by ETi = 0.257d1.778 for several species (ENQUIST et al., 1998). The integration of ETi values in a given sample plot (Aj in square meters) allowed estimating ETi,j per unit area (L/m2/d or simply mm/d) through the equation ETi,j = ΣETi/ Aj, where i = 1, 2, …, n and j = 1, 2, …, k.

3 Tree cover estimation

The tree cover of each EVU was obtained through photo interpretation of satellite images from Bing Maps obtained from the Open Layers plugin (Kalberer & Walker, 2019) using the QGIS software (QGIS, 2018).

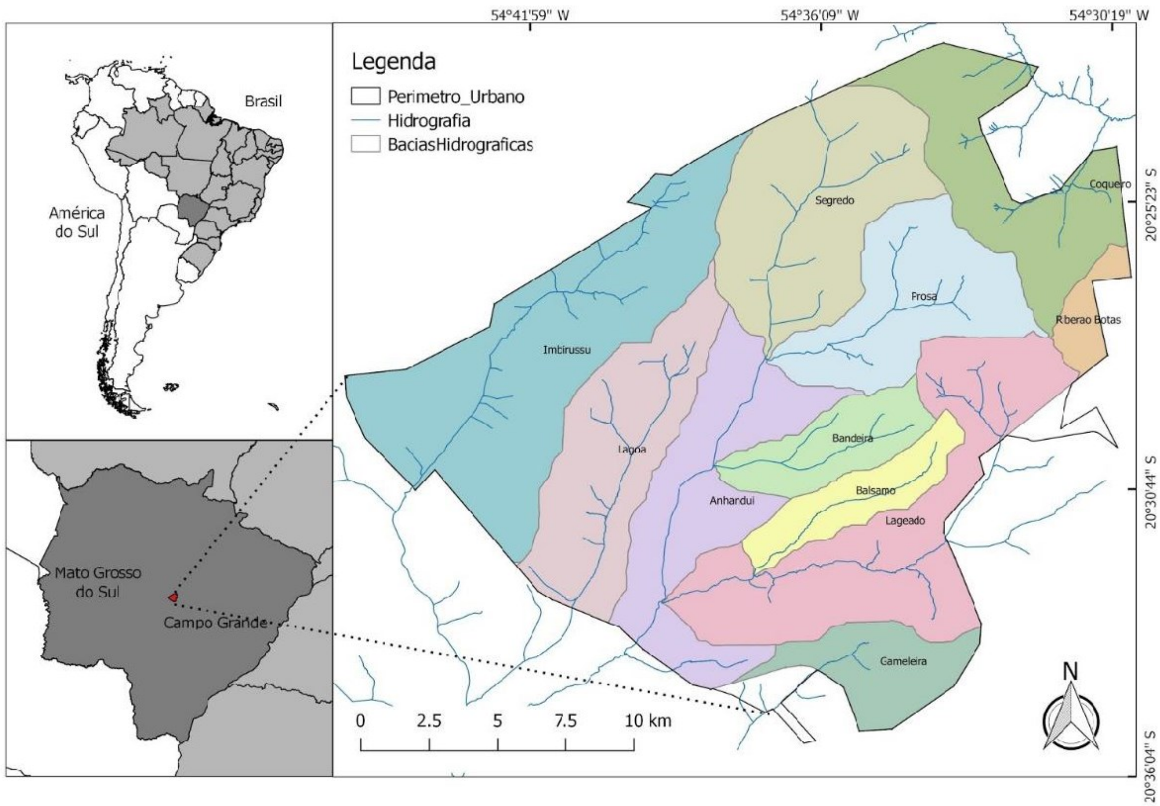
Characterization of the study area

Field data were obtained during the autumn and winter of 2018 in Campo Grande, Mato Grosso do Sul, a city of 35,903.53 acres of urban area and an urban population (98.66%) of 776,242 thousand inhabitants (IBGE, 2010). This fact is seen in a population density of 97.22 inhabitants/km² in 2010. As for the climate, Campo Grande is located in the transition range between the subtype (Cfa) humid mesothermal without drought or small drought and the sub - type (Aw) humid tropical, with a rainy season in summer and a dry season in winter.

The urban area is located on the Paraná River Hydrographic Basin, and comprises 11 micro basins (Figure 1). The entire city is located in the neotropical zone belonging to the domains of the Cerrado phytogeographic region, its main physiognomies are: Campo Limpo, Campo Sujo, Cerrado, Cerradão, Alluvial Forest (riparian forest) and areas of Ecological Tension, represented by the contact Cerrado/ Semideciduous Seasonal Forest (PLANURB, 2017).

Image 2

Location of Campo Grande/MS and its division by watersheds in the urban perimeter



Source: Authors

Results and Discussions

Mapping of Urban Green Spaces (EVU)

The EVU mapping shown in Image 3a allowed observing the distribution of typologies in the urban area of Campo Grande. All of them are linked to the system of hydrological channels of the city, with the Linear Parks (PL) typology distributed along the banks of these streams, and the Park and Protected Areas (P) and Conservation Units (UC) typologies are distributed in springs or close to stream confluences.

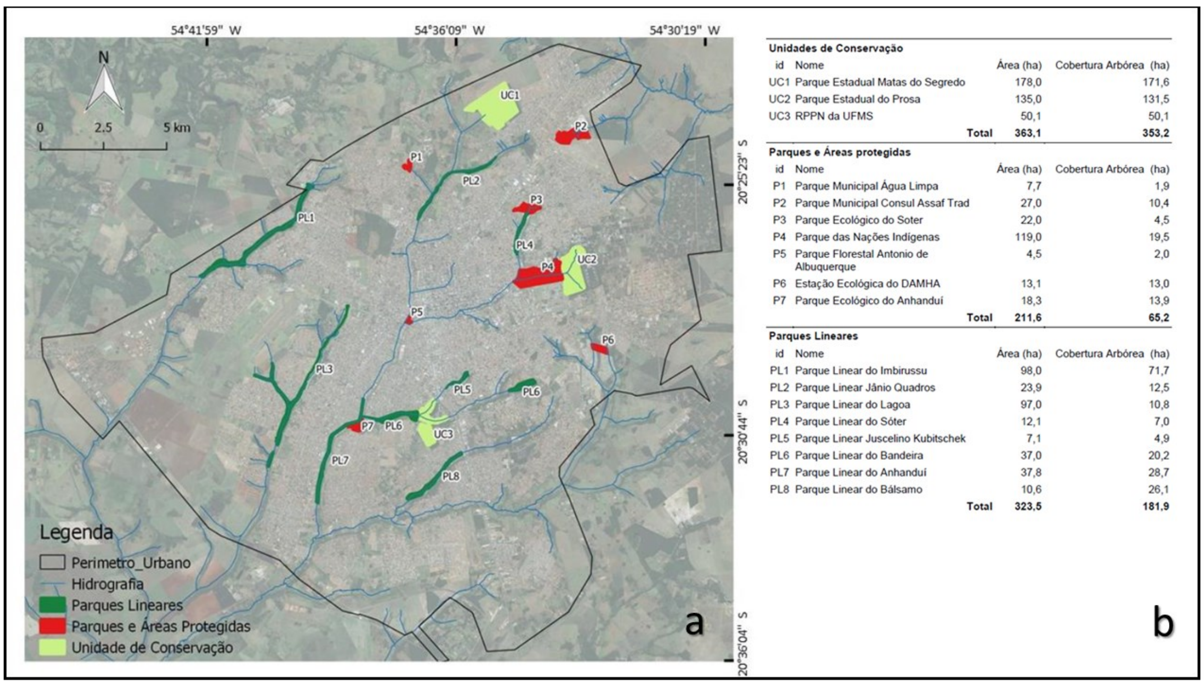
Despite the large number of Linear Parks throughout the city, which allows connectivity between urban natural fragments, serving as ecological corridors, it is observed that the streams in the central region of the city are unprotected by vegetation, without the presence of Linear Parks. This makes it more susceptible to flooding and heat islands. Parks and Protected Areas are sparsely distributed throughout the urban area.

Some watersheds such as the Imbirussu Basin and the Lagoa Basin do not have any EVU of this type, which also impairs drainage, intensifies the effects of urban heat islands (IUC), in addition to cultural losses for regions with a lack of space of leisure in contact with nature.

Mapping is of utmost importance because it makes it possible to spatially perceive the deficiency of EVU in certain regions of the city, restricting the population to access to nature, a form of environmental injustice. Therefore, these regions represent opportunities for expanding the EVU system in Campo Grande, not only because of their importance to the urban ecosystem, but also because of the need for more EVU for the population. Image 3b shows the list of all EVU aimed at nature conservation in Campo Grande (PLANURB, 2017).

Image 3.

a. *Urban Green Spaces aimed at nature protection in Campo Grande/MS Linear Parks: PL1 - Imbirussu Linear Park; PL2 - Jânio Quadros Linear Park; PL3 - Lagoa Linear Park; PL4 - Sóter Linear Park; PL5 - Juscelino Kubitschek Linear Park; PL6 - Bandeira Linear Park; PL7 - Anhanduí Linear Park; PL8 - Bálsamo Linear Park. Parks and Protected Areas: P1 - Água Limpa Municipal Park; P2 - Consul Assaf Trad Municipal Park; P3 - Sóter Ecological Park; P4 - Indigenous Nations Parks; P5 - Antônio Albuquerque Forest Park; P6 - Damha Ecological Station; P7 - Anhanduí Ecological Park. Conservation Units: UC1 - Matas do Segredo State Park; UC2 - Prosa State Parks; UC3 - RPPN of the UFMS.* ***b.*** *Description of the absolute areas of the EVU currently present in Campo Grande, MS*



id	Nome	Área (ha)	Cobertura Arbórea (ha)
Unidades de Conservação			
UC1	Parque Estadual Matas do Segredo	178,0	171,6
UC2	Parque Estadual do Prosa	135,0	131,5
UC3	RPPN da UFMS	50,1	50,1
	Total	**363,1**	**353,2**
Parques e Áreas protegidas			
P1	Parque Municipal Água Limpa	7,7	1,9
P2	Parque Municipal Consul Assaf Trad	27,0	10,4
P3	Parque Ecológico do Soter	22,0	4,5
P4	Parque das Nações Indígenas	119,0	19,5
P5	Parque Florestal Antonio de Albuquerque	4,5	2,0
P6	Estação Ecológica do DAMHA	13,1	13,0
P7	Parque Ecológico do Anhanduí	18,3	13,9
	Total	**211,6**	**65,2**
Parques Lineares			
PL1	Parque Linear do Imbirussu	98,0	71,7
PL2	Parque Linear Jânio Quadros	23,9	12,5
PL3	Parque Linear do Lagoa	97,0	10,8
PL4	Parque Linear do Sóter	12,1	7,0
PL5	Parque Linear Juscelino Kubitschek	7,1	4,9
PL6	Parque Linear do Bandeira	37,0	20,2
PL7	Parque Linear do Anhanduí	37,8	28,7
PL8	Parque Linear do Bálsamo	10,6	26,1
	Total	**323,5**	**181,9**

Source: PLANURB

Field survey

Using the random sampling stratification methodology, five EVU were selected for field survey.

Image 4. a.

Soter Linear Park. At the top, the location and sampling line (20°26'34” S/ 54°34'54” W); lower left, external view of the sampling area; bottom right, typical vegetation of the sampled plots (internal view of the park); ***b****. Imbirussu Linear Park. At the top, the sampling line (20°26'22” S/ 54°40'34” W); bottom left, external view of the sampling area; bottom right, typical vegetation of the sampled plots (internal view of the park*

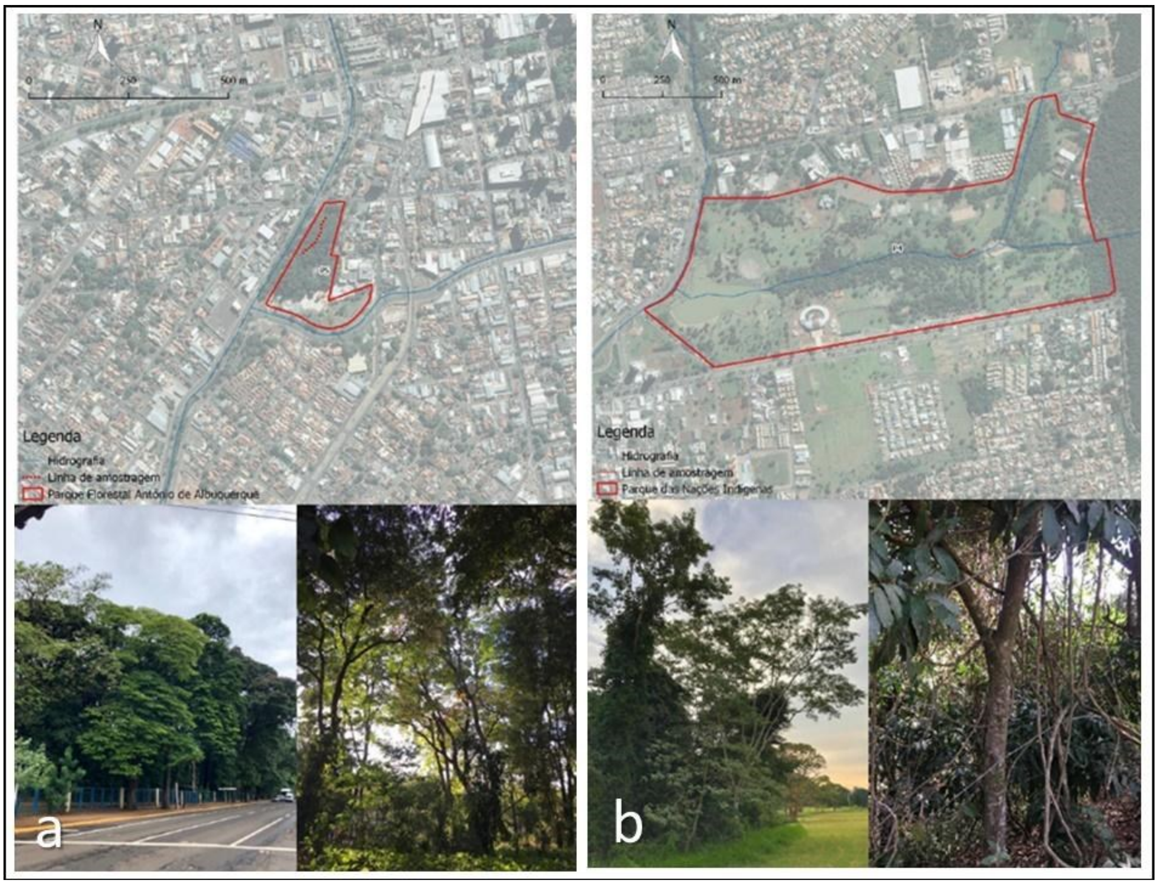
Source: Authors

The Soter Linear Park (Image 4) corresponds to caption PL4, in Image 3, and it was created in 2003 with the purpose of accommodating the bed of the water course of the Sóter stream; it allows the drainage and infiltration of rainwater and conserves riparian vegetation by maintaining local biodiversity. In addition to following the watercourse, this park serves as an ecological corridor between two other EVU, the Sóter Ecological Park and the Parque das Nações Indígenas. Its area is completely unobstructed, allowing free access to the stream, and the only existing structure is a walking track along the entire park.

Created in 2011, the Parque Linear do Imbirussu, (image 4.b) identified as PL1 in Image 3, is the most recently implemented EVU among those analyzed. The Park is intended to recover the ecosystem and maintain the ecological balance of the Imbirussu stream microbasin, in addition to supplying the lack of natural spaces and leisure in this region of the city. The Park has a Forest Garden and an Environmental Education Center (CEA), where one of the seedling production nurseries for urban tree planting is located.

Image 5. a.

Antônio Albuquerque Forest Park. At the top, location of the sampling line (20°28'06” S/ 54°37'21” W); bottom left, external view of the sampling area; bottom right, typical vegetation of the sampled plots (internal view of the park); ***b****. Parque das Nações Indígenas. At the top, location and sampling line (20°27'12” S/ 54°34'12” W); bottom left, external view of the sampling area; bottom right, typical vegetation of the sampled plots (internal view of the park)*



Source: Authors

Image 5a shows the Parque Florestal Antônio Albuquerque, also known as Horto Florestal, identified in Image 3 as P5. The park began in 1912 when the area was reserved for the Intendancy, with its own characteristics of vegetation and where two branches of streams come together to form the Anhanduizinho river. In 1923 it was named as a Park, where species were produced that served for afforestation of the city of Campo Grande and surroundings. The area has facilities that promote leisure, sports and culture, in addition to being in the Special Zone of Cultural Interest (ZEIC) of Campo Grande (PLANURB, 2017).

The Parque das Nações Indígenas (Image 5.b) identified as P4 in Image 3 was created in 1993 from the expropriation by the State Government of several farms and land on the banks of streams located in the area. It is the largest urban leisure park in Campo Grande, it promotes recreational, sports, educational and cultural activities, as well as museums and areas for events. Part of the original vegetation of riparian forest along the stream is preserved and most of the vegetation in the park consists of lawns and ornamental and fruit trees, derived from the landscaping project.

Image 6

Private Natural Heritage Reserve of the Federal University of Mato Grosso do Sul. At the top, location of the RPPN and the sampling line (20°30'36" S/ 54°36'55" W); below, on the left, external view of the sampling area; below, on the right, typical vegetation of the sampled plots (internal view of the park).

Source: Authors.

Image 6 shows the Private Natural Heritage Reserve (RPPN), under the domain of the Federal University of Mato Grosso do Sul - UFMS, in Campo Grande. It was recognized as a Conservation Unit (UC) in 2003, with the aim of preserving primitive, semi-primitive, recovered or developing conditions, formed by Cerrado in different stages and riparian forest. The highest medians of d occurred in Parks and Protected Areas, as expected, while the highest count occurred in the UFMS RPPN Conservation Unit. The highest medians of d were found in parks

(Table 1a) since these EVU are mostly the oldest, with mature trees. The Parque Florestal Antônio Albuquerque, with the highest median and interquartile (interval between Q2 and Q3) of d is the oldest EVU, created in 1912 (PLANURB, 2017).

Field data analysis

As expected by the TME (Enquist & Bentley, 2012), Table 1b demonstrates that the P(d) distributions of the analyzed EVUs do not follow a Gaussian model for a significance level of 5%. Based on this result, the analyzes were based on non-parametric tests (medians and interquartile ranges).

Image 7 presents the distributions of P(d) as a function of d for each EVU analyzed, showing that in fact they do not follow a Gaussian model, but can be adjusted by power laws, whose parameters are presented in Table 3. The distribution can be generalized by TME as P(d) = βdα for α = -2 (Enquist & Bentley, 2012). The empirical data obtained from the EVU evaluation showed α ranging from -1.228 to -2.434, around the value expected by TME, and R2 ranging from 0.869 to 0.986 (Table 3). The general model obtained, based on the power law adjustment for all EVU analyzed is P(d) = 1363.9d-1.616 (Table 3).

Table 1

a. *Q2 (25%) and Q3 (75%) median and quartile values for the d values measured in the EVU.;*

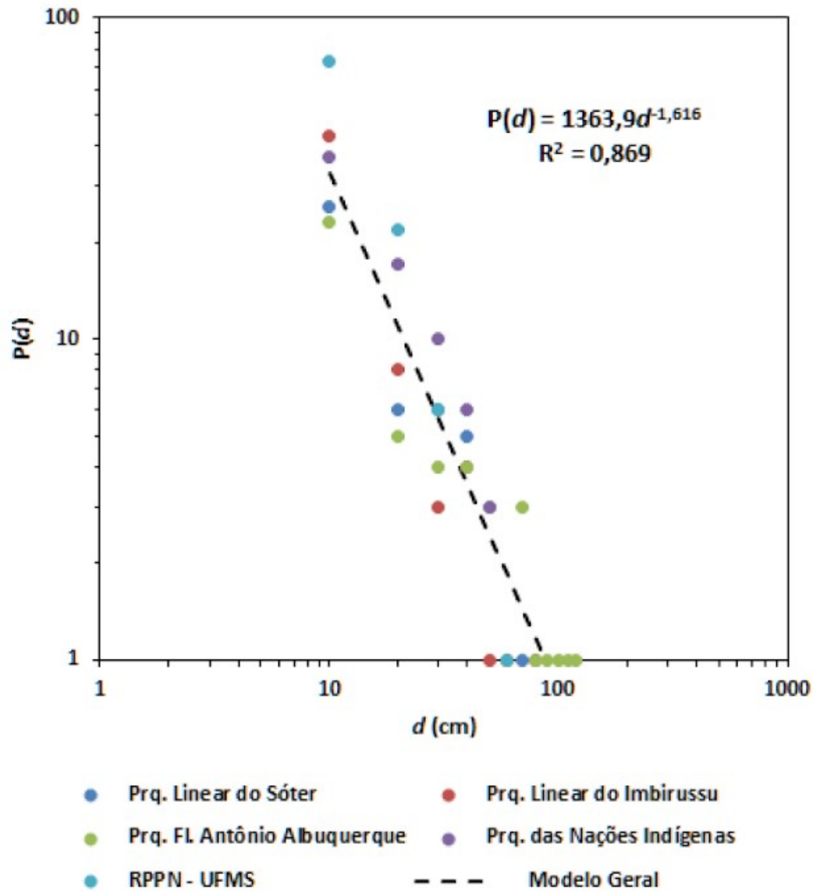
b. *Normality tests of the P(d) distribution of the sampled EVU typologies*

a	Prq. Linear do Sóter	Prq. Linear do Imbirussu	Prq. Fl. Antônio Albuquerque	Prq. das Nações Indígenas	RPPN - UFMS
n	44	61	48	73	102
Mediana	5,09	4,77	11,8	9,87	5,41
Q2	1,926	2,39	3,26	4,305	3,10
Q3	23,47	12,7	40,11	20,5	10,82

b	Prq. Linear do Sóter	Prq. Linear do Imbirussu	Prq. Fl. Antônio Albuquerque	Prq. das Nações Indígenas	RPPN - UFMS
n	44	61	48	73	102
Shapiro-Wilk W	0,7756	0,6815	0,7933	0,876	0,7363
p(normal)	8,94E-07	3,20E-10	9,18E-07	3,33E-06	3,03E-12
Anderson-Darling A	3,297	6,946	3,557	2,937	5,933
p(normal)	2,14E-08	3,29E-17	5,04E-09	1,87E-07	1,07E-14
p(Monte Carlo)	0,0001	0,0001	0,0001	0,0001	0,0001
Jarque-Bera JB	37,63	128,7	19,02	14,29	951,5
p(normal)	6,76E-09	1,16E-28	7,43E-05	0,0007868	2,38E-207
p(Monte Carlo)	0,0011	0,0001	0,004	0,0072	0,0001

Image 7

Frequency P(d) as a function of d (DAP) of the EVU analyzed and trend adjustment (General Model) independent of the EVU.



The higher the value of d (the larger the individual) the lower its frequency in a given forest area. In Image 7, the RPPN - UFMS has a higher frequency of individuals with lower values of d in relation to the other EVU, as well as the Parque Florestal Antônio de Albuquerque has a lower relative frequency of smaller individuals. In a way, this is reflected in the estimated exponents (Table 4), given that EVU with lower α values (more negative) tend to show a higher frequency of smaller individuals, whereas EVU with higher α values (less negative) indicate a higher frequency relative to larger individuals.

The result of the KW test (chi-square: 18.12, p = 0.00115) suggests that at least one EVU typology differs from the others in terms of d (Table 2). Dunn's post-hoc test (Table 4) shows that among the EVU of the same typology, the medians of d are not distinguished (e.g. Parque Linear do Sóter in relation to Parque Linear do Imbirussu and Parque Florestal Antonio Albuquerque in relation to Parque das Indigenous Nations). The Parks and Protected Areas typologies differ from the other two typologies, being the Linear Parks and the Conservation Unit RPPN - UFMS similar in terms of d.

Table 2 a

Statistical regression parameters of the function P(d) = βdα for the sampled EVU typologies; B. Dunn's post-hoc test of d values for the five EVU samples. In bold and underline significant differences at the 5% level

a

	β	α	R^2
Prq. Linear do Sóter	799,63	-1,501	0,904
Prq. Linear do Imbirussu	2.654,2	-1,895	0,928
Prq. Florestal Antônio de Albuquerque	293,23	-1,228	0,876
Prq. das Nações Indígenas	1.292,7	-1,484	0,961
RPPN - UFMS	23.823,0	-2,434	0,986
Modelo Geral	1363,9	-1,616	0,869

b

	Prq. Linear do Sóter	Prq. Linear do Imbirussu	Prq. Fl. Antônio Albuquerque	Prq. das Nações Indígenas	RPPN - UFMS
Prq. Linear do Sóter	-	0,8632	**<u>0,01077</u>**	**<u>0,03837</u>**	0,8226
Prq. Linear do Imbirussu	-	-	**<u>0,003332</u>**	**<u>0,01332</u>**	0,9688
Prq. Fl. Antônio Albuquerque	-	-	-	0,4609	**<u>0,001069</u>**
Prq. das Nações Indígenas	-	-	-	-	**<u>0,004485</u>**
RPPN - UFMS	-	-	-	-	-

The TME predicts that the power law exponent of the distribution of d can be an indicator of environmental disturbances such as fire, deforestation or the successional stage by changing the values of α (see e.g. Figure 14.12 in Enquist & Bentley, 2012). As shown in Table 3, the smaller (more negative) the α value, the greater the frequency of smaller individuals and the smaller the occurrence of larger individuals.

On the other hand, the similarity of the distributions in the form of the probability distribution function P(d) = βdα between the typologies suggests the possibility of estimating values of ecosystem services from d for EVU in general and for other patches of cerrado phytophysiognomies in rural areas of the Pantanal, Cerrado and Amazon biomes.

When analyzing the results of the Parks and Protected Areas, it is noted that, despite the 70-year difference between the creation of the two parks, the medians of d are not distinguished, indicating that characteristics such as the level of protection may be responsible for similarities or differences between the distribution of d in EVU. In contrast, the RPPN was similar to the Linear Parks, although different in its structure and level of protection. In this case, it is reasonable to suggest that such similarity results from the fact that both are young forests and in early stages of ecological succession (Enquist et al., 1998; Enquist & Bentley, 2012).

Estimation of Forest Carbon Stock and Evapotranspiration

From the values of d obtained in the field and the calculation of B in a delimited space, ECF = 0.5*B (in tons) was obtained. Similarly, the ET Total was estimated for each EVU based on the relationships between the scales of d and water transport through the xylem. All these values were calculated based on the tree cover values of each EVU (Table 5a).

The d values allowed to extrapolate the ECF and ET calculations for each type of EVU currently present in Campo Grande (Image 3, Table 5b). Calculations were performed by estimating the median and interquartile by aggregating values measured by typology: i) two linear parks, ii) two forest parks and iii) one conservation unit. The latter was added to the Linear Park typology as they are statistically indistinguishable (Table 4). It should be noted, however, that in the long term and in the absence of interventions or drastic changes, all typologies should reach the climax phase of the ecological succession, which could confer less variability in the probability distribution function of d among the identified typologies.

Table 3.

a. *Medians (Q2 and Q3 interquartiles) of ECF and ET calculated for each EVU analyzed;* ***b.*** *Medians (interquartiles 25% and 75%) of ECF and ET calculated for each type of EVU extrapolated for the entire municipality of Campo Grande. Prq= park*

a

Tipologias de EVU	Cobertura Arbórea (ha)	ECF (toneladas)	ET Total (m^3/d)
Prq. Linear do Sóter	7,01	1.082,7 (556 ; 2.304,3)	500,7 (280,2 ; 897,7)
Prq. Linear do Imbirussu	71,69	15.004,1 (1.043,9 ; 41.383,1)	7.527,1 (999,7 ; 13.033,2)
Prq. Fl. Antônio Albuquerque	1,96	2.653,1 (563,9 ; 7.630,0)	628,0 (213,0 ; 1437,8)
Prq. das Nações Indígenas	19,52	3698,0 (2.143,5 ; 9.148,0)	2642,0 (1.209,1 ; 3442,7)
RPPN - UFMS	34,34	1527,1 (3.435,7 ; 9.489,6	3480,1 (2.654,4 ; 5.518,1)

b

EVU	Área Total (ha)	Cobertura Arbórea (ha)	ECF (toneladas)	ET (m^3/d)
Parques Lineares	323,5	181,9	17.507,9 (8.049,1 ; 119.508,3)	13.225,6 (8.472,6 ; 25.803,8)
Parques e Áreas Protegidas	211,6	65,2	18.908,0 (9.690,4 ;105.241,0)	10.417,3 (6.534,0 ; 29.369,6)
Unidades de Conservação	363,1	353,2	33.995,5 (15.629,1 ; 232.052,4)	25.680,5 (16.451,4 ; 50.103,9)

Currently, the EVU areas in Campo Grande total 898 hectares (2.5% of the urban area in 2010), which, according to calculations based on the data in Tables 1 and 7, store between 33,368.5 and 456,801.7 tons of C in the form of forest biomass, and are responsible for daily atmospheric humidification of the order of 31,458.0 to 105,277.3 m3 of water. This forestry service of atmospheric humidification by removing interstitial water from the soil (excess when soil is soaked or saturated) helps to reduce the local temperature, therefore helping to combat the formation of IUC, as well as mitigating the impacts of floods.

If the EVU area was, for example, quadrupled in the coming years, this would represent only 10% of the urban area in relation to 2010 and would bring positive effects in relation to living C decrease (ECF ranging between 133 thousand and 1.82 million tons of carbon) and in relation to ET which would increase to values between 125,900 and 421,100 m3/d. On the other hand, future studies must be carried out to identify suitable urban spaces for the implementation of new EVU, and that also incorporate sociocultural services.

Considering that climate change (Hansen et al., 2012) should accentuate the occurrence of extreme rain and heat events in the region (Bergier et al., 2018), the approach proposed here, based on Ecohydrology and Ecological Metabolic Theory , represents one of the feasible implementation solutions for adapting and mitigating greenhouse gas emissions and the impacts of these changes on the urban population that will live in Campo Grande in the coming decades.

Conclusions

This study presents the mapping of EVU and its respective ecosystem services in Campo Grande, revealing the deficiency of these environments in certain sectors of the city. Statistical analyzes show that the values obtained with the field survey do not follow a Gaussian model, but can be modeled by power law distributions through the Ecological Metabolic Theory (EMT). The study also reveals that ecosystem regulation services, translated into ecohydrological concepts such as ECF and ET in the urban area, can be estimated by integrating DBH data (d).

It was found that the EMT has great application potential, but also limitations, as it allows evaluating flows and stocks in a system only for intervals (interquartiles) that contain the median of the distribution. This is due to the fact that the power law distribution does not allow the use of the mean and the standard deviation, but only the median and the interquartile. However, these statistical uncertainties result from the intrinsic dynamics of complex systems that unfold in nature and not from the observation or measurement performed. The phenotypic plasticity, that is, the slightly divergent macroscopic manifestation of EMT, can be understood as a function of the environment or the stage of ecological succession. However, the use of the interquartile to evaluate natural processes with a power law distribution guarantees a reliable margin of uncertainty, which can be scaled independently of the woody species and its successional stage, seasonality and environment.

The results presented here suggest that scaling the EVU from 2.5% to 10% of the urban area in Campo Grande may have important consequences for the adaptation of future urban generations and for the mitigation of climate change. Therefore, the geolocation of new EVU should be the result of research in the near future.

References

Bergier, I. et al. (2018). Amazon rainforest modulation of water security in the Pantanal wetland. *Science of The Total Environment. 619–620*: 1116-11251. DOI: 10.1016/j.scitotenv.2017.11.163

Bergier, I., Salis, S. M., & Mattos, P. P. (2016). Metabolic scaling applied to native woody savanna species in the Pantanal of Nhecolândia. In I. Bergier, & M. L. Assine, (Eds.), *Dynamics of the Pantanal Wetland in South America.* (The Handbook of environmental chemistry, v. 37) (pp. 133-144). Switzerland: Springer International Publishing. DOI: 10.1007/698_2014_326

BRASIL. Ministério do Meio Ambiente. SNUC – Sistema Nacional de Unidades de Conservação da Natureza: Lei nº 9.985, de 18 de julho de 2000; Decreto nº 4.340, de 22 de agosto de 2002; Decreto nº 5.746, de 5 de abril de 2006. Plano Estratégico Nacional de Áreas Protegidas: Decreto nº 5.758, de 13 de abril de 2006. Brasília: MMA, 2011.

Bustamante, M. M. C., Nardoto, G. B., Pinto, A. S.; Resende, J. C. F., Takahashi, F. S. C., & Vieira, L. C. G. (2012). Potential impacts of climate change on biogeochemical functioning of Cerrado ecosystems. *Brazilian Journal of Biology*, São Carlos, *72*(3): 655-671. DOI:10.1590/S1519-69842012000400005.

Coomes, D. A., & Allen, R. B. (2009). Testing the Metabolic Scaling Theory of tree growth. *Journal of Ecology, 97:* 1369-1373. DOI: 10.1111/j.1365-2745.2010.01719.x

Coomes, D.A, Lines, E.R., & Allen, R.B. (2011). Moving on from metabolic scaling theory: hierarchical models of tree growth and asymmetric competition for light. *Journal of Ecology*, *99:* 748–756. DOI: 10.1111/j.1365-2745.2011.01811.x

Davies, Z. G., Dallimer, M., Edmondson, J. L., Leake, J. R., & Gaston, K. J. (2013). Identifying potential sources of variability between vegetation carbon storage estimates for urban areas. *Environmental Pollution*., *183*: 133-142. DOI: 10.1016/j.envpol.2013.06.005

Escobedo F., Varela, S., Zhao, M., Wagner, J. E., & Zipperer, W. (2010). Analyzing the efficacy of subtropical urban forests in offsetting carbon emissions from cities. *Environmental Science & Policy 13*(5): 362-372. DOI: 10.1016/j.envsci.2010.03.009

Enquist, B. J., & Bentley, L. P. (2012). Land Plants: New Theoretical Directions and Empirical Prospects. Metabolic Ecology: A Scaling Approach. John Wiley and Sons. https://doi.org/10.1002/9781119968535.ch14.

Enquist, B. J., Brown, J. H., & West G. B. (1998). Allometric scaling of plant energetics and population density. *Nature*, 395: 163-165. DOI: 10.1038/25977.

Enquist, B. J. et al. (2015). Scaling from Traits to Ecosystems: Developing a General Trait Driver Theory via Integrating Trait-Based and Metabolic Scaling Theories. *Advances in Ecological Research*, 52: 249-318. DOI: 10.1016/bs.aecr.2015.02.001

Hammer, Ø., Harper D. A. T., & Ryan, P. D. (2001). PAST: Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologia Electronica, 4*(1): 9. http://palaeo-electronica.org/2001_1/past/issue1_01.htm.

Hansen, J., Sato, M., & Ruedy R. (2012). Perception of climate change. *PNAS* |: E2415–E2423. Disponível em: <https://www.pnas.org/content/109/37/E2415>. DOI:

10.1073/pnas.1205276109

Higa, R. C. V., Cardoso D. J., Andrade, G. de C., Zanatta, J. A., Rossi, L. M. B., Pulrolnik, K., Nicodemo, M. L. F., Garrastazu, M. C., Vasconcelos, S. S., & Salis, S. M. (2014). Protocolo de medição e soma de biomassa e carbono florestal. *EMBRAPA Florestas*. https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1011409/protocolo-de-medicao-e-estimativa-de-biomassa-e-carbono-florestal.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). Censo Brasileiro de 2010. Rio de Janeiro: IBGE, 2012.

Kabisch, N., Qureshi, S., & Haase D. (2015). Human–environment interactions in urban green spaces — A systematic review of contemporary issues and prospects for future research. *Environmental Impact Assessment Review* 50: 25-34. DOI: 10.1016/j.eiar.2014.08.007.

Kalberer P., & Walker M. (1994). Open Layers plugin for QGIS. Disponível em: https://github.com/sourcepole/qgis-openlayers-plugin. Acesso: 09 de maio de 2019.
NIKLAS, K. Plant Allometry: The Scaling of Form and Process. Niklas, Karl. Bibliovault OAI Repository, the University of Chicago Press.

Niemela, J. (2014). Ecology of urban green spaces: The way forward in answering major research questions. *Landscape and Urban Planning* 125: 298–303. DOI: 10.1016/j.landurbplan.2013.07.014

Nowak, D. J. (1994). Atmospheric carbon dioxide reduction by Chicago's urban forest. In E. G. McPherson, D. J. Nowak, R. A. Rowntree, (Eds.), *Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. General Technical Report* (pp. 83–94). https://www.fs.usda.gov/psw/topics/urban_forestry/products/cufr_57_EM95_25.pdf

Nowak, D. J., & Crane, D. E. (2002). Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution*, 116: 81-389. DOI: 10.1016/S0269-7491(01)00214-7

ONU – Nações Unidas no Brasil. (2018). Objetivo de Desenvolvimento Sustentável (ODS) 11. DOCUMENTOS TEMÁTICOS. p. 47. Brasília.

PLANURB - Agência Municipal de Meio Ambiente e Planejamento Urbano (2017). Perfil Socioeconômico de Campo Grande/Instituto Municipal de Planejamento Urbano – PLANURB. 24. Ed. Rev. Campo Grande.

QGIS Development Team (2018). QGIS Geographic Information System. Open Source Geospatial Foundation Project. Disponível em: <http://qgis.osgeo.org>

Salis, S. M., Lehn, C. R., Mattos, P. P., Bergier, I., & Crispim, S. M. A. (2014). Root behavior of savanna species in Brazil's Pantanal wetland. *Global Ecology and Conservation* 2: 378-384. DOI: 10.1016/j.gecco.2014.10.009

Sampath, S. (2005). Sampling Theory and Methods. Alpha Science International. Harrow, UK. Ed. 2.

Tavares, F. S. B., Bergier, I., & Guaraldo, E. (2021). Análise cienciométrica de espaços verdes urbanos e seus serviços ecossistêmicos. *Interações (Campo Grande), 22*(1): 103-114. DOI: 10.20435/inter.v22i1.2596

West, G. B., Brown, J. H., & Enquist, B. J. A (1997). General Model for the Origin of Allometric Scaling Laws in Biology. *Science,* 276: 122-126. DOI: 10.1126/science.276.5309.122

West G. B., Enquist B. J., & Brown J. H. (2009a). A general quantitative theory of forest structure and dynamics. *Proceedings of the National Academy of Sciences (PNAS)* 106(17): 7040-7045. DOI: 10.1073/pnas.0812294106.

West G. B., Enquist B. J., & Brown J. H. (2009b). Extensions and evaluations of a general quantitative theory of forest structure and dynamics. *Proceedings of the National Academy of Sciences (PNAS) USA*, 106(17): 7046–7051. DOI: 10.1073/pnas.0812303106