

FEDERAL UNIVERSITY OF SÃO CARLOS
SÃO CARLOS CAMPUS
POSTGRADUATE PROGRAM IN WILDLIFE CONSERVATION

THIAGO DA COSTA DIAS

**HABITAT SELECTION BY CAPYBARAS (*Hydrochoerus hydrochaeris*) IN
NATURAL AND ANTHROPIC LANDSCAPES IN BRAZIL**

São Carlos - SP
2019

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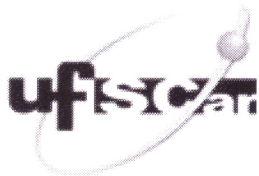
THIAGO DA COSTA DIAS

HABITAT SELECTION BY CAPYBARAS (*Hydrochoerus hydrochaeris*) IN
NATURAL AND ANTHROPIC LANDSCAPES IN BRAZIL

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Conservation, to obtain the title of
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Conservation.

Orientation: Prof. Dr. Vlamir José
Rocha

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“I wish to speak a word for Nature, for absolute freedom and wildness, as contrasted with a freedom and culture merely civil—to regard man as an inhabitant, or a part and parcel of Nature, rather than a member of society.”

Henry David Thoreau

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ABSTRACT

Wildlife distribution is driven by a variety of intrinsic and extrinsic factors that limit species to habitats with the adequate resources and conditions to maintain their survival. The selection of specific habitats by wildlife is modified by, among other things, predator's presence and human-related disturbance, which is proved to have directly effects in wild species behavior. Thus, species as the capybara (*Hydrochoerus hydrochaeris*), that occurs both in natural and anthropic areas, may present different patterns of habitat selection since "risk" is generated by different agents in these landscapes. This study aims to model and compare selection of the main components of capybara habitat (forests, water sources and open areas dominated by grasses / shrubs) in natural landscapes of the Brazilian Pantanal, where predator's abundance is massive and human density is low, and anthropic areas of São Paulo state, where the opposite occurs, using Resource Selection Functions (RSF). The results shown that, in Pantanal, areas within and nearby forest patches were not selected by capybaras and the species presented preferences for areas close to water sources. This response is mainly related to the great predation risk in this landscape full of predators. In human dominated landscapes of São Paulo state, capybaras presented high selection for areas within and nearby forest patches and close to water sources, especially during the day when human disturbance is more pronounced. The high selection for areas within forest patches is probably related to the Brazilian Spotted Fever (BSF) epidemiology and the depredation of water springs in São Paulo state. Besides that, according to the results founded by this study it is recommended that selection for open areas with grasses / shrubs in anthropic/agricultural landscapes should be modeled by including food items in different classes, considering the temporal dynamics of crop fields, which can generate more refined results.

Keywords: capybara; Resource Selection Function; habitat selection, Brazilian Spotted Fever; landscape of fear.

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1. INTRODUCTION

The distribution of wildlife is driven by the interaction of biotic and abiotic factors that limit species to habitats with the adequate resources and conditions to maintain their survival (GYSEL & LYON, 1987; HALL et al., 1997; HIRZEL & LE LAY, 2008). The selection of these habitats is affected by a variety of intrinsic (e.g. nutrition, behavior) and extrinsic factors, such as competition and predation (SENFT et al., 1987; WIENS, 1989; MANLY et al., 2002; HIRZEL & LE LAY, 2008). Besides these factors, Laundré et al. (2001) and Altendorf et al. (2001) introduced the term “landscape of fear” to explain the effect of fear (as avoidance to predation risk) in behavior and time allocation by animals in different habitats, which may lead, for example, in changes in foraging patterns (LAUNDRÉ et al., 2010).

In anthropic landscapes, human-driven disturbance affects wildlife in a similar way to predation risk (BERGER et al., 1983; FRID & DILL, 2002). Since situations generated by human presence can lead to lethal effects on fauna (e.g., hunt, vehicle collisions and domestic animal’s attacks; JAYAKODY et al., 2008; STANKOWICH, 2008; HUIJSER et al., 2013), some wild species alter their behavior in the presence of human activities (DYER et al., 2001; BOYDSTON et al., 2003; FORTIN & ANDRUSKIW, 2003; MANOR & SALTZ, 2005; BLANC et al., 2006).

Among these animals, stands out the capybara (*Hydrochoerus hydrochaeris* Linnaeus, 1766), a generalist species that occurs both in natural and anthropic landscapes (HERRERA & MACDONALD, 1989; VERDADE & FERRAZ, 2006; VARGAS et al., 2007). This herbivore is the largest rodent in the world, reaching about 79 kg according to Nowak (1999), although heavier animals have already been found in agricultural landscapes of São Paulo state (*Pers. Obs.*). The landscape arrangement is essential to determine capybara’s distribution (QUINTANA, 1996; CORRIALE et al., 2013) and the species usually occurs in habitats with three main components: water bodies, forest patches and open areas dominated by grasses (ALHO & RONDON, 1987). Water is an essential resource for this species, being used for thermoregulation, mate and as a refuge from predator attacks (MACDONALD, 1981; HERRERA, 1985;

MOREIRA et al., 2013a). Forest patches provide shelter from the day heat and a resting place at the night (ALHO & RONDON, 1987). In agricultural landscapes of Piracicaba's river basin (São Paulo state, Brazil), Ferraz et al. (2007) also argue that forest patches furnish protection from hunting. The open areas are used for grazing by capybaras, which mainly feed on grasses in these habitats (BARRETO & QUINTANA, 2013).

These animals seem to modify their behavior in anthropic landscapes (BARRETO & QUINTANA, 2013), becoming more nocturnal in agricultural areas and pasturelands (LORD 1991; FELIX et al., 2014) than they are in natural ecosystems (Brazilian Pantanal: ALHO et al., 1987; Venezuelan Llanos: BARRETO & HERRERA, 1998). The fact of capybara's natural predators being found in low abundance in anthropic areas (FERRAZ et al., 2009; CAMPOS-KRAUER et al., 2014), and the presence of disturbances associated with human activities (e.g., hunt, persecution by domestic animals, agricultural machinery noises) may be important factors influencing capybara's habitat use in these anthropic landscapes, where the species is associated with public health problems.

Understanding capybara's habitat selection is crucial to investigate Brazilian Spotted Fever (BSF) epidemiology, the most lethal rickettsiosis in the world. Capybaras use areas in common with humans (ROCHA et al., 2017) and are responsible for carrying and maintaining large numbers of the tick species (*Amblyomma* spp.) considered biological vector and natural reservoir for the bacterium *Rickettsia rickettsii*, responsible for the great majority of the BSF cases in Brazil (LABRUNA, 2013). The São Paulo state government, through the Health Secretary, recorded 982 cases of this disease from 1985 to middle 2018, with 49% resulting in death (SAO PAULO STATE SECRETARY FOR HEALTH, 2018). During this last few decades the same region also experienced a rapid growth in capybara populations, mainly linked to agriculture expansion (FERRAZ et al., 2007; MOREIRA et al. 2013a; ROCHA et al., 2017).

Wildlife habitat selection can be investigated through the integration of remote sensing / GIS (Geographic Information System) techniques and GPS-tags technology, which is allowing ecologists to monitor and advance in questions

related to this theme (KAYS et al., 2015; STABACH et al., 2016). Several modelling techniques have been developed to investigate the relationships established between wildlife and their environment (LÓPEZ-LÓPEZ et al., 2016, AVGAR et al., 2016; STABACH et al., 2016), with emphasis on the use of Resource Selection Functions (RSF; MANLY et al., 2012). Fitted in a use-availability framework (NORTHRUP et al., 2013) this approach compares the habitats used by tracked animals (using the GPS-tag data) with its availability, measured by a sample of random points generated within a pre-determined area (MANLY et al., 2002. JOHNSON et al., 2006).

Therefore, the objective of this work was to investigate the differences in habitat selection between capybara groups in the Brazilian Pantanal (natural landscape) and anthropic landscapes in the São Paulo state, Brazil, using Resource Selection Functions (RSF).

2. METHODS

2.1. Study Area

A total of 11 capybara groups were monitored in Brazil, being four in the Pantanal and seven in municipalities of São Paulo state (SP), in the Southeastern region (Figure 1). The Pantanal is the biggest wetland in the world and much of its distribution occurs in Mato Grosso (MT) and Mato Grosso do Sul (MS) states, both in Brazil. The landscape in Pantanal is constituted by mosaics of vegetation and flooded areas (ALHO & RONDON, 1987; SILVA et al., 2000) and the climate is classified as Aw (savanna climate) according to Köppen's classification (CADAVID-GARCIA, 1984), with relatively high temperatures throughout all the year and two well-defined season, the dry winter and the rainy summer, where flooding usually occurs (SILVA et al., 2000). In this big wetland, rainfall ranges from 800 to 1400mm/year, with most of the rains (70%) occurring between November and March (SILVA et al., 2000).

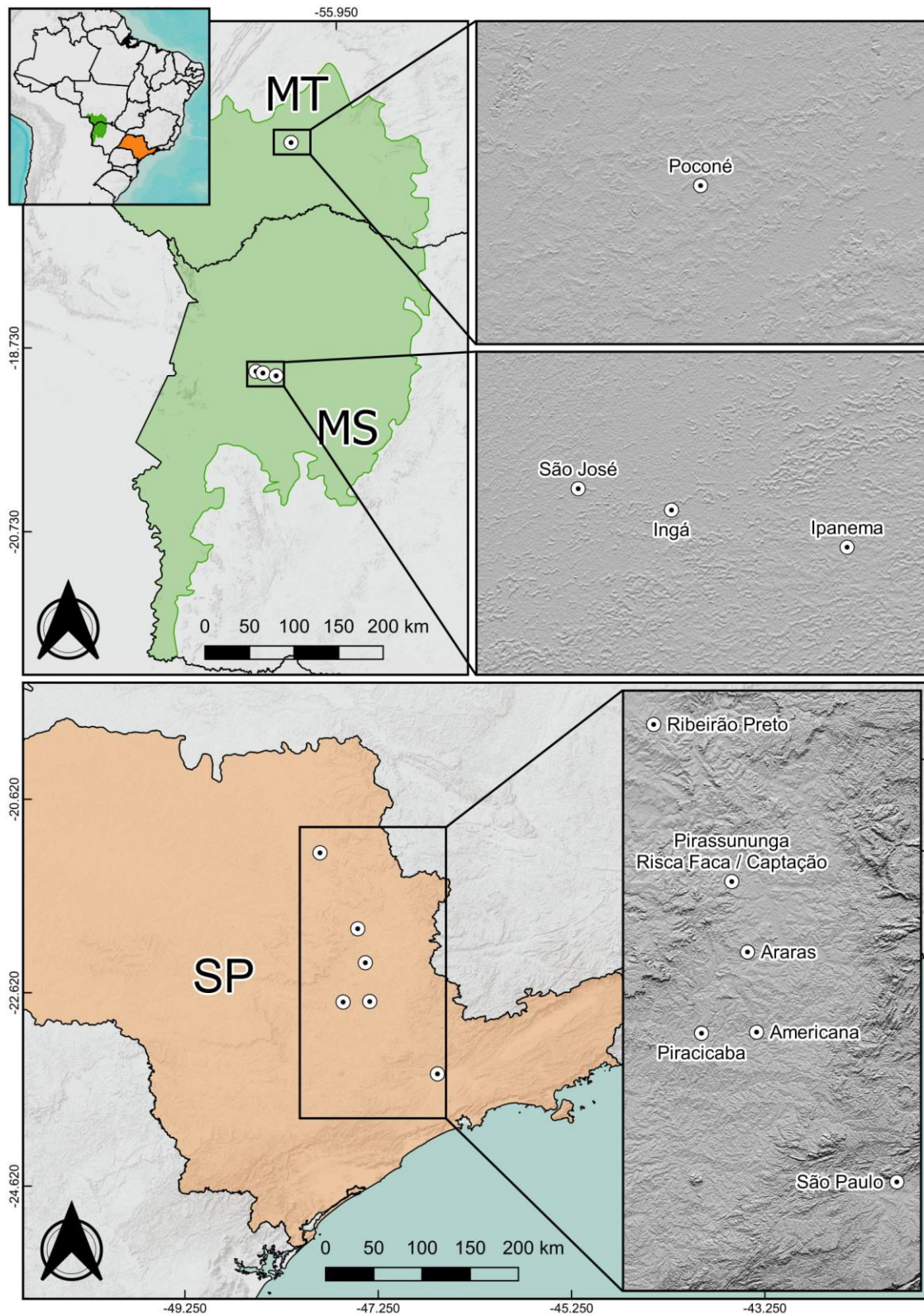


Figure 1. Study areas in the Brazilian Pantanal and São Paulo state. The Brazilian Pantanal limits, contained in Mato Grosso (MT) and Mato Grosso do Sul (MS) states, are represented by the green color. The São Paulo state (SP) is represented in orange (Geographic Coordinate System: WGS 84 / EPSG 4326).

The Brazilian Pantanal maintains an extraordinary biodiversity with high indexes of species richness and abundance (HECKMAN, 1999; SWARTZ, 2000; HARRIS et al., 2005; ALHO et al., 2011). Presenting large areas of natural vegetation and well-structured ecological communities, this biome still counts on the massive presence of capybara predators, such as jaguars (*Panthera onca*), pumas (*Puma concolor*), small cats (*Leopardus* spp.), crab-eating foxes (*Cerdocyon thous*), caimans (*Caiman yacare*) and the snake *Eunectes murinus*, known as anaconda (SCHALLER & VASCONCELOS, 1978; CALLE et al., 1994; POLISAR et al., 2003; TROLLE, 2003; ALHO et al., 2011; MOREIRA et al., 2013a). The Pantanal is also located in a region with small human population density (Mato Grosso state = 3.36 hab/km², Mato Grosso do Sul state = 6.86 hab/km²: IBGE, 2010), which reduces the negative effects of human activities on wildlife.

Capybara groups were monitored in two sub-regions of Pantanal: Poconé, in the northern Pantanal (Mato Grosso state); and Nhecolândia, in the south (Mato Grosso do Sul state). According to Silva et al. (2000), the vegetation in Poconé is mostly composed by seasonal semideciduous forest (an Atlantic Rainforest phytophysognomy, 12.6%), and cerrado (phytophysognomy of the Cerrado biome, 12.9%), besides open fields (flooded or not) dominated by grasses and shrubs (41.5%). In Nhecolândia, vegetation is dominated by two Cerrado phytophysognomies, cerrado and cerrado *stricto sensu* (33.5% and 11.9%, respectively), besides open fields (44.2%). Capybara groups monitored in this study were counted by direct observation, as done by other authors (MACDONALD, 1981; ALHO et al., 1987; HERRERA & MACDONALD, 1989; YÁBER & HERRERA, 1993; BARRETO & HERRERA, 1998), and maximum number of individuals ranged from six to 46 (São José = 46; Ipanema = undetermined; Ingá = 30; Poconé = 6).

Unlike the Brazilian Pantanal, São Paulo state underwent a historical process of deforestation that started during the 16th century with the exploration of Brazilwood, being intensified with the industrialization in the 20th century (METZGER, 1998; DURIGAN & RATTER, 2006). Nowadays, São Paulo is one of the highest human populated states in Brazil, with approximately 166 hab/km² (IBGE, 2010). The landscape was converted by human activities into a mosaic

that comprises small patches of Cerrado or Atlantic Rainforest, surrounded mostly by agricultural crops, pasturelands and silviculture (GHELER-COSTA et al., 2002, ARAUJO & ALMEIDA-SANTOS, 2011; ROCHA et al. *in prep*). Forest fragments in São Paulo state present large edge effects and reduced biodiversity (COSTA-NETO et al., 1997), which may directly affect the presence of predators, such as jaguars, pumas and maned wolves (*Chrysocyon brachyurus*; FREITAS, 2016). These species are found in low abundances in the state, being listed as endangered or critically endangered by the “São Paulo state Redbook of Fauna Threatened by Extinction” (BRESSAN et al., 2009). Added to this fact, the combination of water bodies and agricultural crops in rural areas of São Paulo state contributed to the increase of density capybara populations experienced during the last decades (FERRAZ et al., 2007; MOREIRA et al. 2013a; ROCHA et al., 2017). Maximum individuals counted in groups of São Paulo state ranged from 21 to 59 (Americana = 41; Araras = 56; Piracicaba = 59; Pirassununga Risca Faca = 57; Pirassununga Captação = 27; Ribeirão Preto = 23; São Paulo = 21).

In São Paulo state, capybaras were monitored in six municipalities: Americana, Araras, Piracicaba, Pirassununga, Ribeirão Preto and São Paulo. In general, the landscape in these study areas presents small patches of semideciduous seasonal forest surrounded by agricultural crops (predominantly sugar cane and corn), pasture and silviculture and at least one water body (lakes, ponds, etc.) used by the capybara groups. In the municipality of São Paulo, the capybara group was monitored in the Alberto Löfgren State Park, which is mainly composed by dense ombrophilous forest (an Atlantic Rainforest phytophysognomy) and water bodies. The study area in Americana presents agricultural crops but they are located far from the areas used by tracked capybaras. In Ribeirão Preto, the area used by the monitored group has the peculiarity of being surrounded by a fence that prevent the animals from advancing into agricultural crops. According to Koppen’s classification, São Paulo municipality presents Cwa climate (Monsoon-influenced humid subtropical climate), and the other study areas Cwb (Subtropical highland climate, ALVARES, 2013).

2.2. Capybara Capture and Collaring

From 2015 to 2017, one female was captured and GPS-collared (Lotek Iridium Track M 2D Satellite Collar) per group monitored in Pantanal. In São Paulo state where seven groups were monitored, a total of 16 female were captured and collared (SISBIO 43259-2). Animals were anesthetized and captured with the aid of a blowpipe or pneumatic rifle (© Génia, Distinject) in Southern Pantanal study areas (São José, Ingá and Ipanema). It is important to emphasize that in situations of danger, capybaras tend to seek refuge in water (MACDONALD, 1981; PEREIRA & ESTON, 2007; MOREIRA et al., 2013a), which should be considered in case of captures using one of these methodologies, in order to avoid that anesthetized animals drown. In the other areas, capybaras were captured and GPS-collared through corral-type traps similar to those used by Pereira & Eston (2007), automatically triggered by the animals or with a manual trigger. An association of ketamine (2.0 mg/kg) and xylazine (0.2 mg/kg) were used to anesthetize captured animals (Figure 2).

Only female capybaras were equipped with the GPS-tags since groups are mainly composed by animals of this sex (HERRERA & MACDONALD, 1993; VARGAS et al., 2007; GARCÍAS & BAGER, 2009), which also presents lower rates of agonistic interactions (HERRERA & MACDONALD, 1993; SCHALLER & CRAWSHAW, 1981 *apud* FERRAZ et al., 2009), theoretically reducing mortality of GPS-collared animals. Among captured females, only the heaviest ones were equipped with the GPS-collar, since there is a significant correlation between weight and hierarchical position in capybara groups (HERRERA & MACDONALD, 1993). Thus, as capybaras are social animals (HERRERA, 2013), it is expected that the movement of females occupying high hierarchical positions represents the movement of the group majority.



Figure 2. Capybara groups with GPS-collared dominant females. (A) A capybara group using a water spring in a secondary forest area in the São Paulo state. Notes on that are reported in Results and Discussion sections. (B) Two capybaras in the Brazilian Pantanal, including a GPS-collared female. (C) Details of the GPS-collar used to track capybaras. (D) A camera-trap photo of a tracked dominant female with an alpha male in São Paulo state. (E) Capybara group and the GPS-collared female in the water in São Paulo state (Source: Lucas Ribeiro Correa; Vlamir José Rocha; Marcelo Bahia Labruna).

2.3. Habitat Data

High resolution satellite imagery (WorldView-2 © DigitalGlobe) were used to perform land cover classification of study areas through the Random Forest algorithm (GISLASON et al., 2006) and methodology is reported in Appendix 1.

The product of these classifications was used to generate distance layers for three fundamental habitats for capybara's occurrence: 1. Forest; 2. Water; and open areas dominated by 3. Grasses / Shrubs (QUINTANA, 1996; CORRIALE et al., 2013; Table 1).

The forested environments, native or not (primary and secondary forest, silviculture, bamboo, etc.), were mapped through the land cover classification. Forest layers were generated excluding a 50 m edge from the forest patches to generate variability and access selection for areas inside the forest. Native grasses, shrubby vegetation, marshes, pasturelands dominated by exotic grasses (e.g. *Panicum maximum*, *Brachiaria plantaginea*) and agricultural crops (mainly sugar cane *Saccharum officinarum* and corn *Zea mays*) were included in Grasses / Shrubs layers. Lakes, ponds, rivers and streams were included in Water layers. Streams with a width smaller than the spatial resolution of the satellite image (2 m) and covered by forest canopies were not mapped (Table 1).

Normalized Difference Vegetation Index (NDVI) layers were also generated using the same scenes mentioned above (Table 1). The satellite imagery was corrected for "Top-of-Atmosphere" reflectance (UPDIKE & COMP, 2010) and NDVI was calculated following the band equation present in Tucker & Sellers (1986).

Table 1. Description of distance layers generated for three habitat classes (Forest, Grasses / Shrubs, Water) mapped in the land cover classification and for the NDVI layers. These layers were used as input parameters for the Resource Selection Function models.

<i>Covariate</i>	<i>Description</i>
Distance to Forest	Layer generated excluding 50 m within the forest patch to access forest interior selection. Distances defined as 0 were associated with areas 50 m into the forest patch. The forest border was represented by 50 m results and so on. Several types of forest habitats were represented in this class, such as primary and secondary native forests, silviculture (pine and other silvicultural crops) and bamboo.
Distance to Grasses / Shrubs	Distance to grasses and shrubby vegetation, including native grass fields, marshes, and areas dominated by shrubs. Pasturelands composed mainly by exotic grasses and agricultural crops such as sugar cane and corn were also included in this class.

Distance to Water	Distance to water sources, including rivers, lakes, ponds. Small streams and water springs were not mapped due to satellite data resolution (2 m). Water sources hidden by forest canopy were also not mapped.
NDVI	Normalized Difference Vegetation Index, strongly related to vegetation biomass, productivity and characteristics (PETTORELLI et al., 2005; NOURI et al., 2014). Satellite scenes were corrected for “Top-of-Atmosphere” reflectance following the instructions in the WorldView-2 technical note wrote by Updike & Comp (2010). NDVI was calculated by the equation $(\frac{redband-NIRband}{redband+NIRband})$.

2.4. Data Cleaning

GPS-data with a DOP (Dilution of Precision Parameter) bigger than nine were removed from the analysis (following the parameters in Lotek’s GPS-collar manual) to avoid use geolocations with large spatial errors (LEWIS et al., 2007). Data related to animal’s capture day were removed due to the possible influence of stress in space use (MOA et al., 2001; PONJOAN et al., 2008; MORELLET et al., 2009). Data from capybaras with less than 100 geolocations were also excluded, since it represents only four days of tracking. The GPS-data were rarefied to a 4-hour time interval and categorized in diurnal and nocturnal using the package ‘*mapproj*’ (BIVAND & LEWIN-KOH, 2013) in R environment (R CORE TEAM, 2013).

2.5. Resource Selection Function

Habitat selection was evaluated by comparing the use and availability of habitats through a fine-scale third/fourth-order (JOHNSON, 1980) Resource Selection Function (RSF; MANLY et al., 2002). Habitats availability were determined using a set of random points generated within a predetermined area as in Stabach et al. (2016). For this, buffers were created around GPS-locations with a radius of size equal to the maximum distance displaced by the animal over a 4-hour period (due to temporal resolution of GPS-data). These buffers were then merged across individuals that belonged to the same group. Here, large divided highways in São Paulo state varying from 32 to 44 m (Ernesto Paterniani,

Luis de Queiroz and Anhanguera) were taken as barriers to capybara's movement since tracked animals did not cross them, and habitats across these highways were removed.

For each tracked animal, a sensitivity analysis was carried out following Northrup et al. (2013) to set the number of random points per "use" point (GPS-location). An RSF was fitted for each number of availability points per use point (1, 2, 3, 5, 10, 20, 30 or 50) and the process was repeated 100 times to calculate the coefficients with 95% confidence interval. It was decided to use 30 random points for each GPS-location, since this number provided stable coefficients and small confidence intervals (Appendix 2). The analysis was performed in R using 'lme4' package (BATES et al., 2014a).

Habitat variables (Distance to Forest, Distance to Water, Distance to Grasses / Shrubs and NDVI) were tested using Pearson's correlation test in R and excluded if highly correlated (Pearson's $r > 0.65$). All layers were standardized by z-score $([x - \bar{x}]/\sigma_x)$ to facilitate comparisons across landscapes and cross-time periods. The quadratic terms of all habitat variables were included into the models to test for non-linear relationships.

Habitat selection was modeled for two different landscapes (natural and anthropic) and time periods (day and nighttime) applying a generalized linear mixed-effects logistic regression, following the equation:

$$\omega(x_i) = \exp(\beta + \beta_1 x_{1i} + \dots + \beta_n x_{ni} + \gamma_i)$$

where $\omega(x_i)$ was the RSF, β_n was the coefficient for the n th predictor habitat variable x_n , and γ was the random intercept for the animal i (MANLY et al., 2002; GILLIES et al., 2006, STABACH et al., 2016). The random effects were incorporated into the model since it has been shown that doing this it is possible to better account for the differences between individual preferences. In addition, the use of random effects into the model allows the inclusion of unbalanced sampling designs (GILLIES et al., 2006). These random effects were nested ("individual", inside "study area", inside "landscape") to get coefficients at landscape level. A hierarchical approach was used to account for non-independence of individual movements (STABACH et al., 2016). Habitat

selection was modelled using the *lme4* package (BATES et al., 2014) in R software.

2.6. Candidate and Top-ranked Models

Five candidate models were created and ranked (Table 2) for each landscape and time-period using Akaike's Information Criterion (AIC; Burnham & Anderson, 2002). All models containing habitat variables were compared to Null Model using chi-squared test in R. Coefficients of the top-ranked model that overlap zero were considered statistically insignificant.

Table 2. Model structure and number of input variables (K).

<i>Model</i>	<i>Structure</i>	<i>K</i>
Null		3
Forest	Distance to Forest + (Distance to Forest) ²	5
Open Areas	Distance to Grasses / Shrubs + (Distance to Grasse / Shrubs) ²	5
Water	Distance to Water + (Distance to Water) ²	5
Full	NDVI + (NDVI) ² + Distance to Forest + (Distance to Forest) ² + Distance to Grasses / Shrubs + (Distance to Grasses / Shrubs) ² + Distance to Water + (Distance to Water) ²	11

Twenty per cent of presence-only data (GPS-data) were randomly selected to evaluate top-ranked models fit cross-study areas for day and night periods using Spearman rank correlations (r_s) between area-adjusted frequencies (presence-data frequency) and ten RSF spatial bins (BOYCE et al., 2002; STABACH et al., 2016). Models with strong positive correlations would be expected to be the ones with good spatial predictive performance (BOYCE et al., 2002).

2.7. Habitat Selection

Habitat Selection was evaluated through the relative probability of selection for the range of distance to Forest, Grasses / Shrubs, Water, and for the NDVI values using top-ranked model coefficients. Furthermore, spatial predictions were also used to evaluate habitat preferences.

3. RESULTS

3.1. Capybara Capture and Collaring

From the year of 2015 to 2017, a total of 13 GPS-collars collected 17673 geolocations from 20 female capybaras. 7088 geolocations were collected from animals in the Brazilian Pantanal and 10585 from individuals in São Paulo state. The number of locations ranged from 117 to 3939 by individual (*Total: \bar{x} = 883; Pantanal: \bar{x} = 1772; São Paulo: \bar{x} = 662*) and GPS-tags mean fix success was 97.1%, ranging from 88.9% to 100.0% by GPS-collar. The number of days that capybaras were monitored ranged from 33 to 918 (\bar{x} = 273). Maximum distance displaced by individuals in a 4-hour time interval ranged from 268 to 2703 m (\bar{x} = 886 m; Table 3).

Table 3. GPS-tracked capybara's summary table, containing the processed data (see the explanation of data cleaning in methodology). The number of GPS-locations, duration (in days) and the maximum step length (in meters) are displaced by individual.

<i>Ind. ID</i>	<i>Study Area</i>	<i>Start Date</i>	<i>End Date</i>	<i>Duration (days)</i>	<i>GPS-locations</i>	<i>MSL* (m)</i>
1	São José	07/27/2015	01/30/2018	918	3939	1362
2	Ingá	08/22/2017	01/30/2018	161	708	592
3	Ipanema	08/21/2017	01/30/2018	162	722	442
4	Poconé	07/21/2016	01/30/2018	558	1719	1437
5	Americana	06/16/2016	09/04/2016	80	444	596
6	Araras	09/04/2015	11/22/2016	445	274	561
7	Araras	12/02/2015	05/11/2016	161	672	729
8	Araras	06/01/2016	07/20/2016	49	284	394
9	Araras	09/01/2016	12/10/2016	100	138	268
10	Araras	10/04/2017	01/30/2018	118	578	601
11	Piracicaba	10/23/2015	02/21/2016	121	658	2703
12	Piracicaba	07/13/2016	03/03/2017	233	994	1267
13	Pirassununga Risca Faca	10/02/2015	12/05/2015	64	281	1073
14	Pirassununga Risca Faca	06/09/2016	04/23/2017	318	1347	689
15	Pirassununga Captação	10/02/2015	11/04/2015	33	117	805
16	Pirassununga Captação	17/10/2016	21/11/2016	36	161	743
17	Pirassununga Captação	08/10/2017	01/30/2018	173	762	1132
18	Ribeirão Preto	07/19/2015	07/30/2017	743	3218	488
19	Ribeirão Preto	07/31/2017	01/30/2018	183	192	1162
20	São Paulo	10/10/2015	01/08/2016	90	465	671

*Maximum Step Length measured in meters (m).

3.2. Candidate and Top-ranked Models

Likelihood ratio test (χ^2) showed that models with habitat variables (Forest, Open Areas, Water and Full) were significantly different from Null Model. Full Model was top-ranked by AIC in natural and anthropic landscapes during both day and nighttime, showing that all habitat variables were important to predict capybara's habitat selection (Table 4). In natural landscapes of the Brazilian Pantanal, Water model occupied the second position (*Daytime* $\Delta AIC = 1260.4$; *Nighttime* $\Delta AIC = 677.7$). Open Areas model was second best classified in the anthropic landscapes of São Paulo state (*Daytime* $\Delta AIC = 2575.7$; *Nighttime* $\Delta AIC = 847.8$).

Table 4. Model selection for natural and anthropic landscapes (day and nighttime), based on Akaike Information Criterion (AIC). Models with the smaller AIC values are taken as the best to predict capybara's habitat selection. Top-ranked model is highlighted in bold. Likelihood ratio test (χ^2) is also displayed.

Model	K	Natural Day				Natural Night			
		AIC	ΔAIC	ω	χ^2	AIC	ΔAIC	ω	χ^2
Full	11	25887.1		1	5700.4*	23411.9		1	7598.6*
Forest	5	30365.4	4478.3	0	1210.1*	30073.3	6661.4	0	925.3*
Open Areas	5	30982.6	5095.4	0	593.0*	30061.4	6649.5	0	937.1*
Water	5	27147.5	1260.4	0	4428.1*	24089.6	677.7	0	6908.9*
Null	3	31571.6	5684.4	0		30994.6	7582.6	0	

Model	K	Anthropic Day				Anthropic Night			
		AIC	ΔAIC	ω	χ^2	AIC	ΔAIC	ω	χ^2
Full	11	40628.2		1	6678.9*	44548.5		1	259.5*
Forest	5	43675.1	3046.9	0	3620.0*	45984.3	1435.8	0	259.5*
Open Areas	5	43203.9	2575.7	0	4091.2*	45396.3	847.8	0	847.5*
Water	5	45905.3	5277.1	0	1389.8*	45571.3	1022.8	0	672.5*
Null	3	47291.1	6662.9	0		46239.8	1691.3	0	

*p < 0.001

Between non-quadratic habitat variables of top-ranked Full Model, Water was the most important to predict capybara's habitat selection (*Day*: $\beta = -1.52 \pm 0.03$; *Night*: $\beta = -1.91 \pm 0.03$), followed by Forest (*Day*: $\beta = -0.63 \pm 0.04$; *Night*: $\beta = -0.32 \pm 0.04$). Grasses / Shrubs and NDVI was statistically significant only during daytime (*Grasses/ Shrubs*: $\beta = 0.21 \pm 0.05$; *NDVI*: $\beta = 0.21 \pm 0.02$). In the anthropic landscapes of São Paulo state, Grasses / Shrubs was the non-quadratic variable that most explained capybara's habitat selection

for both day and night period (*Day*: $\beta = 1.03 \pm 0.03$; *Night*: $\beta = 0.57 \pm 0.03$), followed by Water (*Day*: $\beta = -0.84 \pm 0.02$; *Night*: $\beta = -0.46 \pm 0.02$), followed by Forest (*Day*: $\beta = -0.83 \pm 0.04$; *Night*: $\beta = -0.08 \pm 0.03$). NDVI was the variable that least explained habitat selection by capybaras in this landscape for day period ($\beta = 0.32 \pm 0.02$), not even being statistically significant during nighttime (Table 5).

Table 5. Resource Selection Function model coefficients (β) for both day and nighttime in natural and anthropic landscapes. Standard errors are displaced within the parentheses.

	<i>Natural</i>		<i>Anthropic</i>	
	<i>Day</i>	<i>Night</i>	<i>Day</i>	<i>Night</i>
NDVI	0.21 (0.02)	0 (0.02)	0.32 (0.02)	0 (0.02)
(NDVI) ²	-0.01 (0.01)	-0.03 (0)	-0.01 (0.01)	-0.15 (0.01)
Forest	-0.63 (0.04)	-0.32 (0.04)	-0.83 (0.04)	-0.08 (0.03)
(Forest) ²	-0.8 (0.04)	-0.72 (0.04)	0.21 (0.01)	-0.04 (0.01)
Grasses / Shrubs	0.21 (0.05)	0.02 (0.04)	1.03 (0.03)	0.57 (0.03)
(Grasses / Shrubs) ²	-0.11 (0.02)	-0.02 (0.01)	-0.36 (0.02)	-0.39 (0.02)
Water	-1.52 (0.03)	-1.91 (0.03)	-0.84 (0.02)	-0.46 (0.02)
(Water) ²	0.32 (0.02)	0.66 (0.02)	0.16 (0.01)	-0.01 (0.02)

Note: Regression coefficients (β) highlighted in boldface are considered statistically significant.

Cross-validation results showed a good predictive performance to almost all study areas, for both day and nighttime. Excluding Ipanema ($r_s = 0.4077$), Pirassununga Risca Faca ($r_s = 0.6571$) and Pirassununga Captação ($r_s = 0.7857$), all study areas presented Spearman rank correlation coefficients bigger than 0.9 during daytime (Table 6). For night period, Ipanema, Araras and Pirassununga Risca Faca showed coefficients bigger than 0.9. São Paulo ($r_s = 0.3152$), Pirassununga Captação ($r_s = 0.4325$) and Ingá ($r_s = 0.4617$) presented the smaller coefficients during this period (Table 6).

Table 6. Cross-validation results for habitat selection models in both day and nighttime are displaced by each study area in natural and anthropic landscapes. Best models-fit were represented by averaged Spearman rank correlation coefficient (r_s) closes to 1.

Study Area	Day (r_s)	Night (r_s)
	<i>Natural Landscapes</i>	
São José	1	0.6
Ingá	1	0.4617
Ipanema	0.4077	1
Poconé	0.9	0.7143
	<i>Anthropic Landscapes</i>	
Americana	0.9487	0.7714
Araras	0.9747	0.9
Picacicaba	1	0.8536
Pirassununga Risca Faca	0.6571	1
Pirassununga Captação	0.7857	0.4325
Ribeirão Preto	0.9289	0.7667
São Paulo	0.9266	0.3152

3.3. Habitat Selection

The selection for forested areas by capybaras differs greatly between natural and anthropic landscapes. Capybaras showed small probability of selection for areas within and close to forest patches in natural landscapes, with probability of selection increasing at mid distances to this habitat (250 m) and decreasing slightly at longer distances (450 m), during both day and nighttime (Figure 3). The opposite occurs in the anthropic landscapes of São Paulo state, with capybaras presenting a higher probability of selection for areas within and close to forest patches than to more distant areas. Selection trend differs between day and night period in this landscape, with the probability of selection for areas within and close to the forest being higher during the day. During nighttime, the selection for areas within/nearby forest patches were not much different than selection for more distant areas (Figure 3).

A high probability of selection for areas close to water were observed in both natural and anthropic landscapes, with selection coefficient decreasing at mid and larger distances (Figure 3). The probability of selection for short-distance areas (less than 100 m) in natural landscapes was slightly higher during nighttime than during the day. The opposite occurred in the anthropic landscapes, with the probability of selection being higher during daytime for short-distance areas to

this habitat. In natural landscapes, for both day and nighttime, the probability of selection suddenly decreases at medium distances (250 m), getting closer to zero at larger distances (500 m). The decline of selection coefficients with increasing of distance to water still happens in anthropic landscapes but is much less pronounced than the observed in natural landscapes (Figure 3).

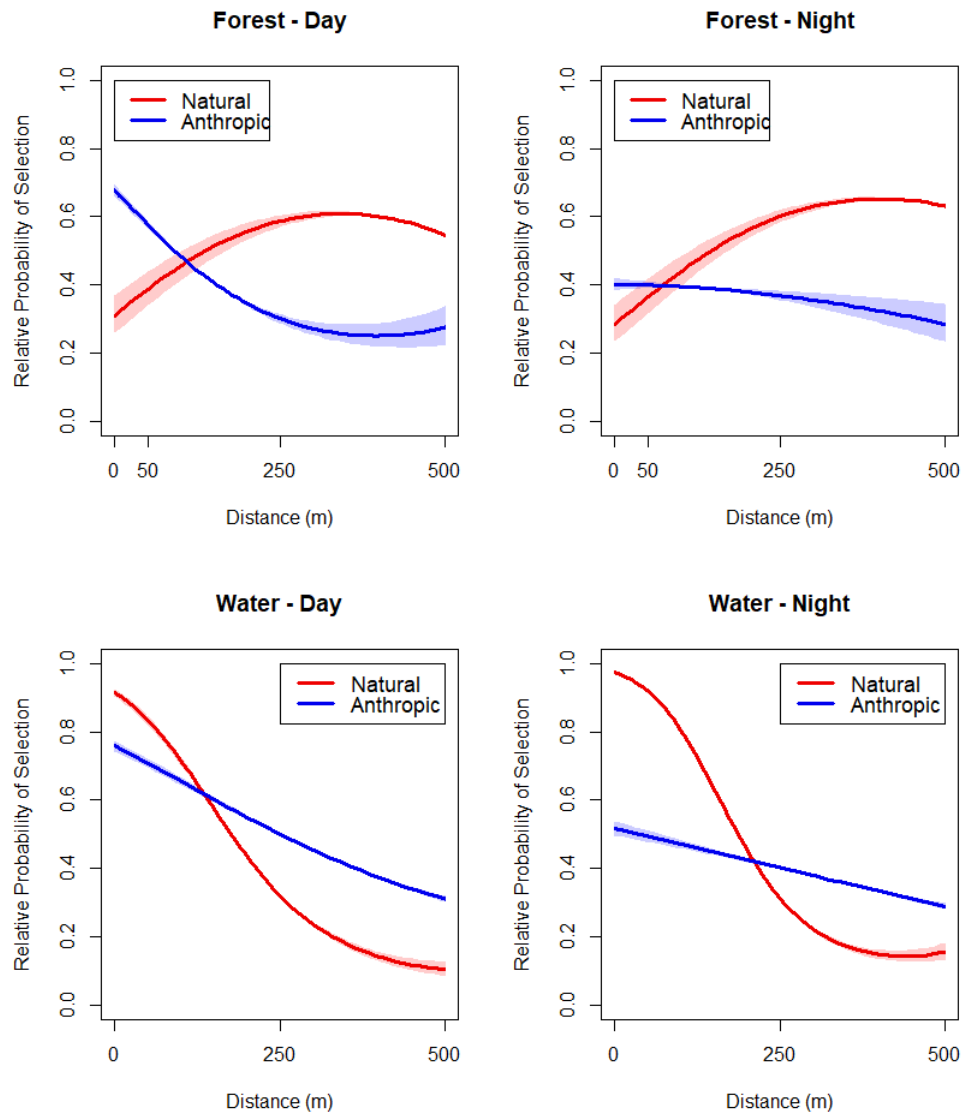


Figure 3. Forest and Water selection during day and nighttime for natural and anthropic landscapes. Distance to these habitats are represented by the x axis. The y axis represents the probability of selection, ranging from 0 to 1. A 50 m area within the forest patch were excluded to access forest border selection, distances defined as 0 are associated with areas 50 m within the forest patch. The forest border is represented by 50 m results and so on.

In natural landscapes, capybaras showed a higher probability of selection for areas close to open areas dominated by grasses / shrubs (less than 50 m), with selection coefficients decreasing as distance increases. A large confidence

interval was observed for grasses / shrubs in natural landscapes during nighttime (Figure 4). For anthropic landscapes of São Paulo state, probability of selection for short distance areas to grasses / shrubs was smaller than what was found in natural landscapes, with selection increasing at areas more distant to this habitat (125 m; Figure 4).

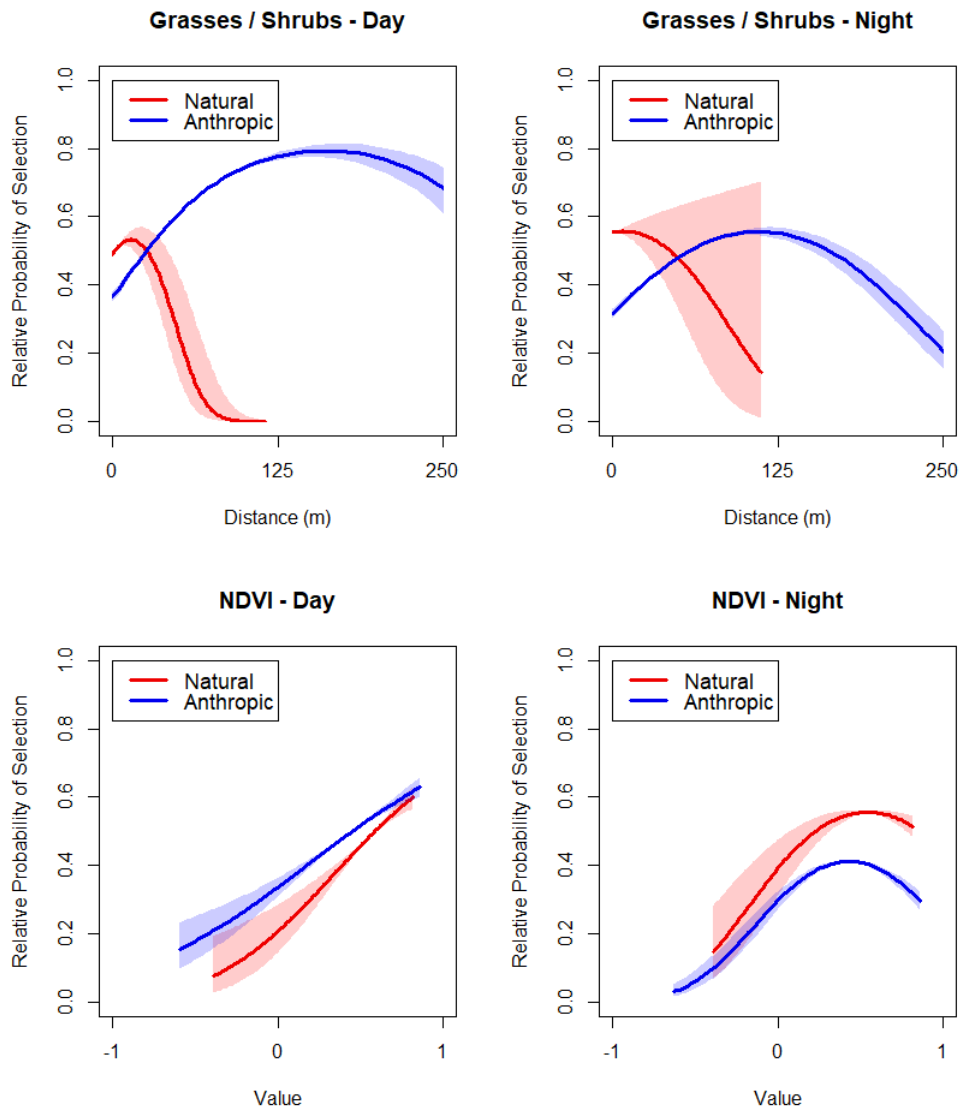


Figure 4. Grasses / Shrubs and NDVI selection during day and nighttime for natural and anthropic landscapes. Distance to Grasses and Shrubs and the NDVI value is represented by the x axis. The y axis represents the probability of selection, ranging from 0 to 1.

NDVI selection did not differ greatly between natural and anthropic landscapes. During the day, the smaller probabilities of selection were found for areas with low NDVI values in both landscapes, with probability of selection increasing with the increase of NDVI (reaching the maximum when NDVI values

were close to 0.7). During night period, the probability of selection for negative NDVI values was also small for both landscapes, and the highest probabilities of selection were found for NDVI values close to 0.4 (Figure 4). In any case, sensitivity analysis pointed that NDVI coefficients did not stabilize, presenting high confidence intervals in most of the study areas (Appendix 2).

RSF spatial predictions showed that, in anthropic landscapes, for both day and nighttime, GPS-data occurred principally in areas with high probability of selection, located mainly near water sources. In general, forest patches presented lower probabilities of selection, but forest borders could present high probability of selection when close to water. Most of the areas dominated by grasses / shrubs with high probability of selection were also located near water sources. Visually, RSF predictions did not present great differences between day and night periods in Pantanal (Figure 5).

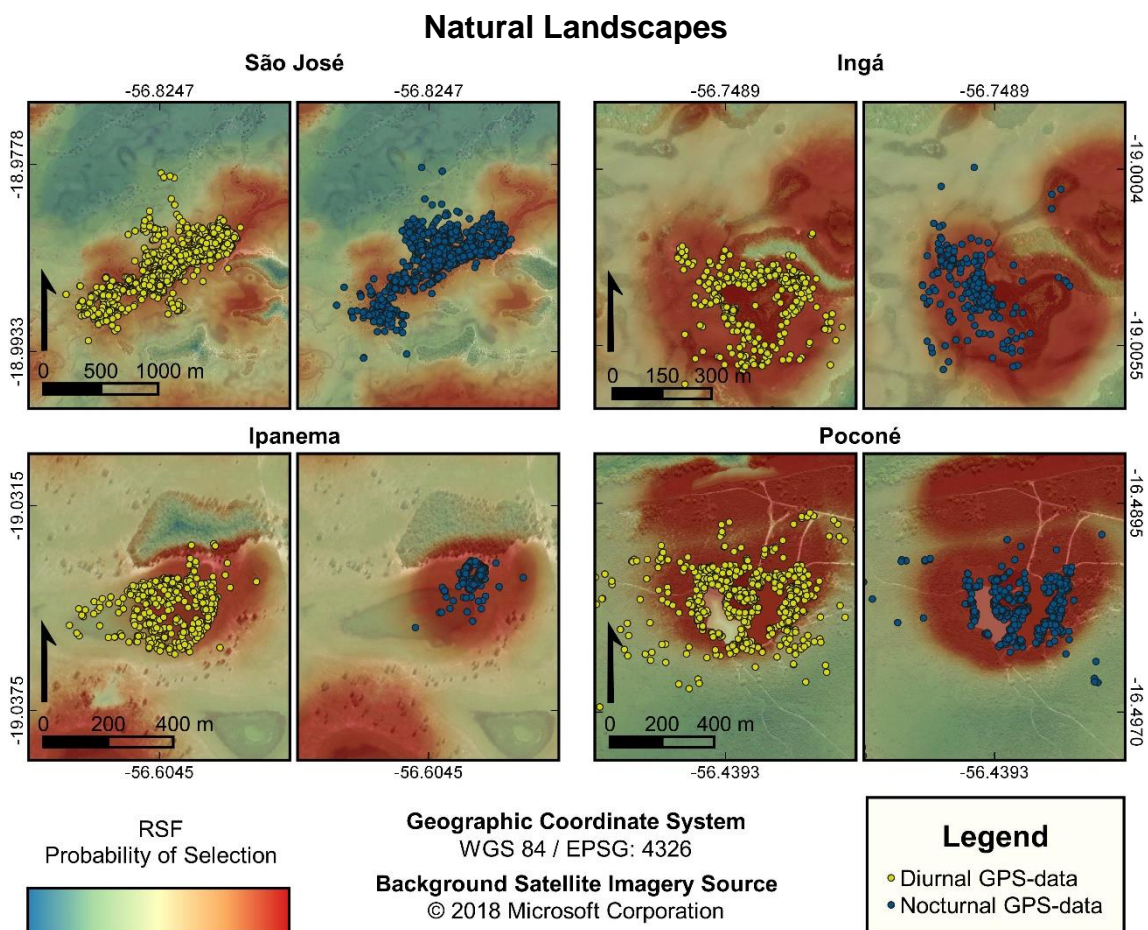


Figure 5. RSF spatial predictions are provided for all study areas during both day and night periods. Warmer colors represent areas with higher probability of selection.

In highly agricultural study areas of anthropic landscapes, such as Araras, Pirassununga - Risca Faca and Pirassununga – Captação, crop fields areas presented high probability of selection during nighttime. In the other agricultural study areas (Piracicaba and Americana), and areas where capybaras did not access crops fields (Ribeirão Preto and São Paulo), selection did not visually differ between day and nighttime. In study areas of São Paulo state that contains larger forest patches (Americana = 44.7 ha and Pirassununga - Captação = 36.3 ha) it was possible to observe that the probability of selection for areas deep inside forest was smaller when comparing to border areas selection. Forest borders presented an even greater selection probability if surrounding water sources (Figure 5).

It was registered the physical depredation of water springs located inside a forest patch under restoration in Araras municipality (São Paulo state) by the capybara group monitored in this local, responsible for turning these small springs into larger water wells (Figure 6).

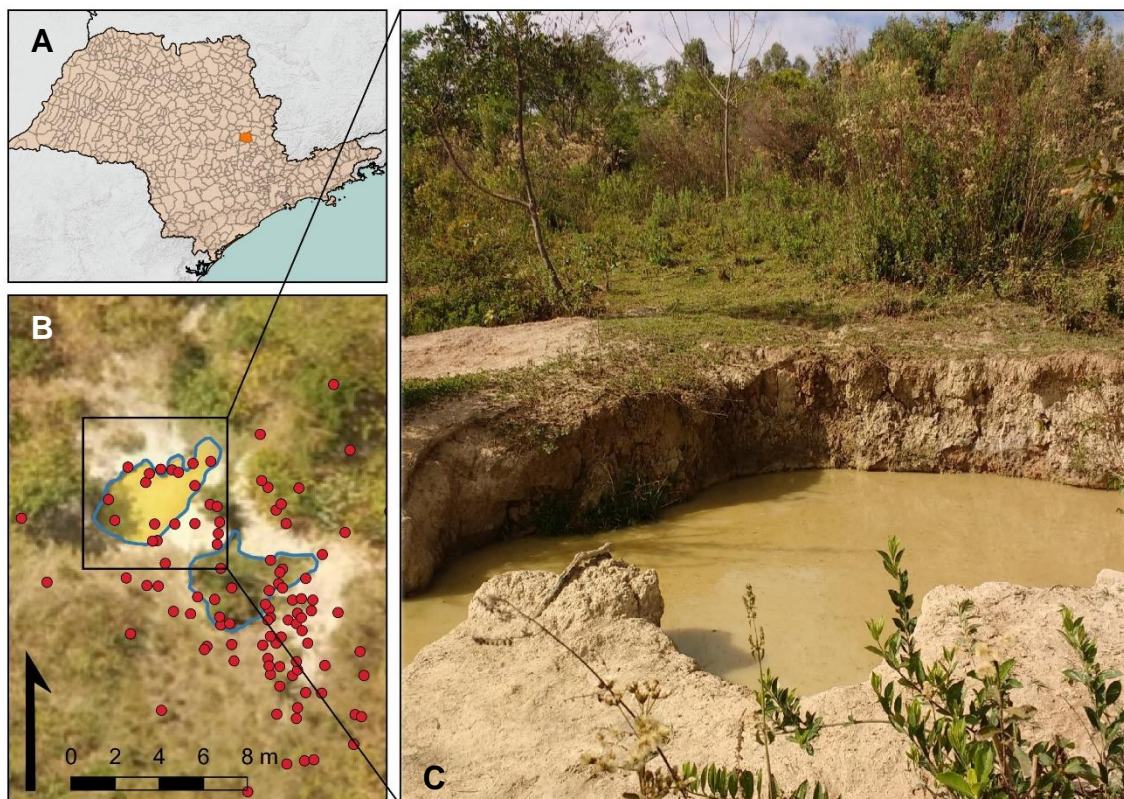


Figure 6. Water spring degradation by a group of capybaras in Araras/SP. (A) São Paulo state highlighting Araras/SP municipality. (B) Drone Image showing GPS-locations (in red) near water springs (blue contour) (Drone Image Source: ZENERO et al., 2017). (C) A water spring degraded by capybaras, turned into a large well. This water spring had a radius of no more than 70 cm before used by the capybara group.

Anthropic Landscapes

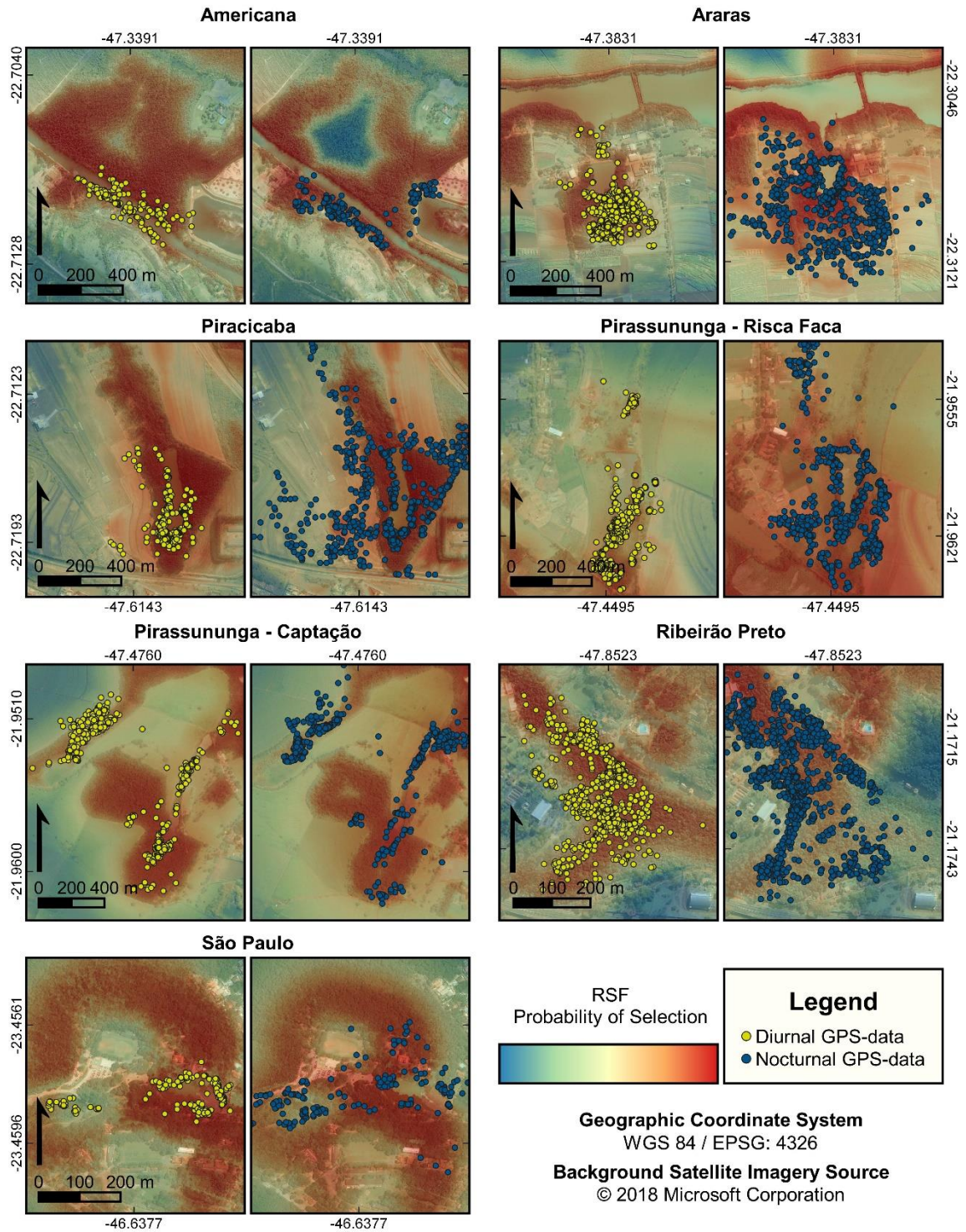


Figure 5. Continued

4. DISCUSSION

4.1. Capybara Capture and Collaring

GPS-collars used in this study (Lotek Iridium Track M 2D Satellite Collar) showed to be efficient for capybara tracking (Table 3), with mean fix success reaching about 97%. GPS-collars collected a great number of locations (max = 3939) and capybaras were able to keep them for more than two and a half years (918 days) without the need of removal. No evidence was found pointing to GPS-collars as a cause of injury or death in tracked capybaras.

4.2. Candidate and Top-ranked Models

Akaike's information criterion (AIC) and qui-squared tests highlighted that the model containing all habitat variables (Full Model) was the best to predict capybara's habitat selection (Table 4). The arrangement of water sources, forest patches and open areas is fundamental to determine capybara's occurrence (QUINTANA, 1996; CORRIALE et al., 2013), with the use of these habitats by the species being extensively described (ALHO & RONDON, 1987; MACDONALD, 1981; HERRERA, 1985; MOREIRA et al., 2013a; FERRAZ et al., 2007; BARRETO & QUINTANA, 2013). Even so, it is the first time that selection for these fundamental habitats was modelled and compared between natural and anthropic landscapes using high-precision GPS-data and a robust statistic method as Resource Selection Functions.

In Pantanal, Water Model occupied the second position in AIC rank (Table 4) and water was the non-quadratic variable most important to explain capybara's habitat selection in top-ranked Full Model, followed by forest (Table 5). In an environment with high predators abundance such as the Brazilian Pantanal (MOREIRA et al., 2013a; SCHALLER & VASCONCELOS, 1978; POLISAR et al., 2003; CALLE et al., 1994; ALHO et al., 2011; TROLLE, 2003), it is expected that predation risk should be a key factor influencing capybara's space use patterns, as showed for other species (LIMA, 1998; KIE, 1999; BROWN, 1999; RIPPLE & BESCHTA, 2003; BROWN & KOTLER, 2004) and cases where predation risk exerted an even greater effect in habitat selection than food abundance or thermal conditions (TOLON et al., 2009).

. The fact of two of the main predators of capybaras in this landscape (jaguars and pumas) present preferences for forested habitats (HOLMES & LAUNDRÉ, 2006; MONROY-VILCHIS et al. 2009; CULLEN-JUNIOR et al., 2013), added to the use of water sources by capybaras to escape from predator attacks (MACDONALD, 1981; PEREIRA & ESTON, 2007; MOREIRA et al., 2013a), highlights these two habitats as being directly influenced by predation risk, explaining their great influence in capybara's habitat selection in Pantanal (Table 5).

Unlike the Brazilian Pantanal, in the anthropic landscapes of São Paulo state, the Open Areas Model occupied the second position (Table 4) and Grasses / Shrubs was the non-quadratic variable that most explained capybara's habitat selection in top-ranked Full model (Table 5), highlighting the importance of open areas used as food sources by capybara groups in this landscape, where predator abundance is relatively lower (FERRAZ et al., 2009; BRESSAN et al., 2009; CAMPOS-KRAUER et al., 2014). In this way, the quality and quantity of food resources may have a strong influence in capybara's habitat selection. Even with human-disturbance being perceived in a similar way to the presence of predators by wildlife (BERGER et al., 1983; GILL et al., 1996; FRID & DILL, 2002), capybaras may shift their activity patterns to access high quality food resources during the hours with less human activities.

4.3. Habitat Selection

Behaviorally complex animals adjust their use of space according to predation-risk (LIMA & DILL 1990, BROWN & KOTLER 2004, CRESSWELL, 2008), since the habitat type influences escape success and predator's detection by prey species (LIMA & DILL, 1990; SHRADER et al., 2008). Capybaras are animals with a complex behavioral repertoire (FERRAZ et al., 2013), that have jaguars and pumas as important predators (SCHALLER & VASCONCELOS, 1978; IRIARTE et al., 1990; CRAWSHAW & QUIGLEY, 1991; ASTETE et al., 2008; CULLEN-JUNIOR et al., 2013; SCHIVO et al., 2015; AZEVEDO et al., 2018). These two big felids present a significant selection for forested habitats (HOLMES & LAUNDRÉ, 2006; MONROY-VILCHIS et al. 2009; CULLEN-

JUNIOR et al., 2013), including those found in the Brazilian Pantanal (CRAWSHAW & QUIGLEY, 1991; DESBIEZ et al., 2009). This fact is probably linked to the low probability of selection for areas within and nearby forest patches by capybara groups in Pantanal (Figure 3). Even if these forested habitats are shown to be important for the species, providing shelter from the day heat and being used as a resting place (QUINTANA & RABINOVICH, 1993; CORDERO & OJASTI, 1981 *apud* MOREIRA et al., 2013b), they were not uniformly used by capybaras in Pantanal, with these animals adjusting their behavior by only selecting forest borders (from the edge to about 50 m into the forest interior) located near water sources (Figure 5), that they can use to quickly escape from predators (MACDONALD, 1981; PEREIRA & ESTON, 2007; MOREIRA et al., 2013a).

The great abundance of predators in Pantanal (SCHALLER & VASCONCELOS, 1978; CALLE et al., 1994; POLISAR et al., 2003; TROLLE, 2003; ALHO et al., 2011; MOREIRA et al., 2013a) should also be linked to the high probability of selection for areas near water by capybaras in this landscape (Figure 3), since this habitat is used by the species as a refuge (PEREIRA & ESTON, 2007; MOREIRA et al., 2013a). Several authors reported the importance of water sources to determine capybara's occurrence (CORDERO & OJASTI, 1981; MURPHEY et al., 1985; MONES & OJASTI, 1986; HERRERA & MACDONALD, 1989; LORD, 1991; QUINTANA et al., 1994, 1998; BARRETO & HERRERA, 1998). In a study carried out by Campos-Krauer et al. (2014) with radio-collared capybaras in the Central Dry Chaco region of Paraguay, 95% of geolocations were found to be closer than 500 meters from water sources. Besides that, in an agricultural area of São Paulo state, Rocha et al. (2017) founded traces of the species in a maximum distance of 430 meters in linear displacement from water sources, showing how dependent these animals are from water sources.

Still about the selection for water sources, since jaguars and pumas present diurnal activity in Pantanal (FOSTER et al., 2013; CRAWSHAW & QUIGLEY, 1991) and due to capybara's thermoregulation behavior (MACDONALD, 1981; HERRERA, 1985; QUINTANA & RABINOVICH, 1993; CORRIALE & HERRERA, 2014), it was expected to find higher probabilities of selection for areas nearby

water sources during the day when comparing to the night period (Figure 3). Anyway, the high probability of selection for areas close to water also during the night should be linked to the fact of capybara groups graze and rest near water during this period (MACDONALD, 1981; HERRERA ,1985; HERRERA & MACDONALD, 1989; OJASTI, 1973 *apud* HERRERA, 2013).

Capybara groups of Pantanal presented high probability of selection for areas nearby grasses / shrubs (Figure 4). This generalist species consumes a great variety of plants in these open habitats (HERRERA & MACDONALD, 1989; QUINTANA et al., 1994; VERDADE & FERRAZ, 2006, DESBIEZ et al., 2011; BARRETO & QUINTANA, 2013; TONETTI & BIONDI, 2015), including at least 26 species during the dry season and 32 during the rains in Pantanal (MAURO & POTT, 1996). Spatial predictions showed that the higher probabilities of selection were found for open areas located near water (Figure 5). Authors already reported the importance of the interaction between these open areas and water sources for capybaras (MACDONALD, 1981; HERRERA & MACDONALD, 1989), since these habitats provides relatively safer conditions based on their distance to water (MACDONALD, 1981; PEREIRA & ESTON, 2007; MOREIRA et al., 2013a).

In anthropic landscapes, capybaras presented higher probability of selection for areas within and nearby forest patches (Figure 3), unlike what was found for the Brazilian Pantanal. Predator's abundance is reduced in São Paulo state (COSTA-NETO et al., 1997; BRESSAN et al., 2009; FERRAZ et al., 2009; CAMPOS-KRAUER et al., 2014) and, even during casual encounters with predators, in these areas capybaras present advantages offered by their larger group size when compared to groups in Pantanal (FERRAZ et al., 2007; VARGAS et al., 2007; PEREIRA & ESTON, 2007), which is responsible for reducing the risk of predation (BERTRAM, 1980; UNDERWOOD, 1982; TURNER & PITCHER, 1986; BERTRAM, 1978 *apud* YÁBER & HERRERA, 1994; MACDONALD et al., 2013). Thus, "risk" in São Paulo study areas should be mainly generated by human-disturbance (DYER et al., 2001; FRID & DRILL, 2002; BONNOT et al., 2002; BOYDSTON et al., 2003), with capybara perceiving forest patches as relatively safer habitats than in Pantanal.

It is worth noting that human activities are more pronounced during daytime in anthropic landscapes where capybaras were monitored in São Paulo state (*Pers. obs.*), same period that the greater probability of selection for areas within the forest patches were found (Figure 3). In this landscape, capybaras were already described as being more nocturnal than in Pantanal (LORD, 1991), pattern that has been observed in other cases in which animals were leaded to nocturnality with the influence of human activities (GAYNOR et al., 2018). In São Paulo state, capybaras are probably spending most of day hours inside forest patches close to water sources, hiding from humans and getting cover from the day heat.

This high probability of selection for areas within forest patches by capybara groups have a directly effect in the Brazilian Spotted Fever epidemiology in São Paulo, the Brazilian state most affected by this deathly zoonosis, recording 915 cases during the last 18 years (SINAN, 2018). Szabó et al. (2007) and Barbieri et al. (2019) founded that forested areas showed higher abundances of the tick *Amblyomma sculptum*, main vector for the bacterium that causes the BSF in São Paulo state (LABRUNA, 2013). Besides that, in laboratory conditions, free-living developmental phases of this tick presented high success in relatively humid environments without water immersion (LABRUNA, 2018), conditions like those found in forested habitats. As such, capybaras and this tick species present a shared habitat preference in São Paulo state, contrary to what was found for capybara groups in Pantanal, which presented lower probability of selection for forested habitats (Figure 3; Figure 5).

In two anthropic study areas that contains larger forest patches, Americana and Pirassununga – Captação, it was possible to observe high selection by capybaras for forest borders (Figure 5). Even with the ecological differences between borders and areas deep inside the forest (MACDOUGALL & KELLMAN, 1992; WIENS et al., 1993; DIDHAN & LAWTON, 1999), the higher selection for border areas by capybara groups is probably mainly linked to the presence of water or open areas with food resources close to this areas, since this was already described for other rodent species, as the wild guinea pig (*Cavia aperea*), the drylands and Córdoba vesper mouse (*Calomys musculinus* and *Calomys venustus*, respectively) and the Azara's grass mouse (*Akodon azarae*), that uses

forest borders as a refuge and adjacent open areas for foraging (CASSINI & GALANTE, 1992; BUSCH et al., 2000; GOMEZ et al., 2011).

In Araras/SP (anthropic area), the capybara group used water springs located inside a forest patch under restoration for thermoregulation and wallowing, behaviors registered in other water sources (HERRERA & MACDONALD, 1989; QUINTANA & RABINOVICH, 1993; CORRIALE & HERRERA, 2014) but never in water springs. The use of this springs by the local large group (max = 56 individuals) was responsible for increasing spring size, that become large water wells over time (Figure 6). This degradation can become worrisome considering the protection of local water resources and could be happening in other forested areas of São Paulo state with similar conditions. This situation had been already reported with wild feral swine (*Sus scrofa*), that causes deleterious impacts to ecosystem processes and functioning (Campbell & Long, 2009). These animals also create wallows used for thermoregulation and ectoparasite control, which result in the watershed degradation and decrease in local water quality. (Campbell & Long, 2009; Kreith, 2007).

Even with several authors reporting capybara's presence in open areas dominated by grasses / shrubs during nighttime (ESCOBAR & GONZÁLEZ-JIMÉNEZ, 1976; SCHALLER, 1983; VERDADE & FERRAZ, 2006; FERRAZ et al., 2007) this study shown that they have a higher probability of selection for areas at mid distance from this habitat (close to 125 m) in anthropic landscapes (Figure 4). To evaluate selection for these food sources in areas of São Paulo state that comprises a mosaic of agricultural crops, pasturelands and other grasses eaten by capybaras, it is recommended to allocate these resources in different habitat variables and evaluated them individually and dynamically to capture changes in capybaras selection over time. The temporal dynamic of agricultural crops should be one of the main factors influencing selection for open areas in these anthropic landscapes, since capybaras are selective grazers in areas with food abundance (GONZÁLEZ-JIMÉNEZ & ESCOBAR, 1975; GONZÁLEZ-JIMÉNEZ, 1977; HERRERA & MACDONALD, 1989; BARRETO & QUINTANA, 2013) such as agricultural landscapes of São Paulo states (FERRAZ et al., 2003; FERRAZ et al., 2007; FELIX et al., 2014). Understand the selection

for these food sources by capybaras is important to reduce conflicts related to the species in the Brazilian Southeast.

Regarding NDVI, even if showed to be an important parameter to model animal's movement in other occasions (WIEGAND et al., 2008; PETTORELLI et al., 2011), this vegetation index was the non-quadratic variable that less explained capybara's habitat selection during the day (tied with grasses / shrubs in natural landscapes), being not even statistically significant during nighttime for both landscape models (Table 5). Also, sensitivity analysis pointed that NDVI coefficients did not stabilized in all study areas (Appendix 2), and behavioral interpretations of this variable should be avoided according to Northrup et al. (2013). One NDVI scene was used by study area due to Worldview-2 satellite data temporal resolution, not capturing temporal changes in this vegetation index, which could be problematic as NDVI vary across seasons (WANG et al., 2003; YANG et al., 2011). In this case, it is recommended to account for temporal dynamics of NDVI when dealing with capybara habitat selection.

5. CONCLUSIONS

Through the integration of GPS-tags and GIS techniques, ecologists are now advancing in questions related to the relationships established between wildlife and their environment. Using Resource Selection Functions (RSF), it was possible to demonstrate the differences in habitat selection by capybara groups in the Brazilian Pantanal and São Paulo state and to obtain empirical understanding that the presence of predators and human-generated risk appeared to exert different effects in capybara's habitat selection. In Pantanal, capybaras select habitats relatively safer, staying close to water sources and far from forest patches. In the anthropic landscapes of São Paulo state, where capybaras are directly influenced by human activities, groups presented high probability of selection for areas within and nearby forest patches, which is linked to public health problems and water springs degradation. Resource Selection Functions seem to be a good methodology to investigate differences in habitat selection by capybaras in Pantanal and São Paulo state, principally in a dynamic

approach that is capable to model food source preferences (agricultural crops, pasturelands, etc.) by capybaras in anthropic landscapes.

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7. APPENDIX 1

High-resolution imagery from the 8-band WorldView-2 satellite (© DigitalGlobe) was used to perform land cover classification using Random Forest algorithm (see GISLASON et al. (2006) for further information about the use of Random Forest on land cover classification).

Two tasseled-cap transformed layers (Brightness and Wetness) were generated using the Kauth-Thomas transformation coefficients present in Yarbrough et al. (2014). Following the equations in Haralick et al. (1973), two texture metrics (Dissimilarity and Second-Moment) were generated through NDVI. The eight bands of WorldView-2 scenes, NDVI, tasseled cap transformed, and texture metrics layers were used as input to the land cover classification (Table 1). The results in Dias et al. (*in prep.*) were used to select these layers. In this work, 1024 layers combination were tested for a WorldView-2 scene classification in the São Paulo state seeking to investigate which combination provides the higher land cover classification accuracy.

Table 1. Land cover classification input data (8-bands WorldView-2 scenes, NDVI, tasseled cap layers and texture metrics).

	<i>Input data</i>		<i>Layer description</i>
<i>Worldview-2 satellite band</i>	Band 1	Coastal Blue	Band 1 (0.400-0.450 μm)
	Band 2	Blue	Band 2 (0.450-0.510 μm)
	Band 3	Green	Band 3 (0.510-0.580 μm)
	Band 4	Yellow	Band 4 (0.585-0.625 μm)
	Band 5	Red	Band 5 (0.630-0.690 μm)
	Band 6	Red Edge	Band 6 (0.705-0.745 μm)
	Band 7	NIR* 1	Band 7 (0.770-0.895 μm)
	Band 8	NIR* 2	Band 8 (0.860-1.040 μm)
<i>Vegetation Index</i>		NDVI	Layer generated following the equation in Tucker & Sellers (1986): $\frac{\text{band } 7_{NIR1} - \text{band } 5_{RED}}{\text{band } 7_{NIR1} + \text{band } 5_{RED}}$
<i>Tasseled cap transformation</i>		Brightness	Layer principally related to the soil reflectance.
		Wetness	Layers related to the terrestrial surface wetness.
<i>Texture metrics</i>		Dissimilarity	$\sum_{n=0}^{N-1} n \{ \sum_{i=1}^N \sum_{j=1}^N p(i, j) \}$
		Angular-second moment	$\sum_i \sum_j \{ p(i, j) \}^2$

*Near Infrared

In total, nine WorldView-2 scenes containing the study areas were classified (Table 2). Pirassununga – Risca Faca and Pirassununga – Captação belong to the same scene. The same for Ingá and São José study areas. A total of 1531 testing polygons (ranging from 102 to 252 by scene) were digitized based on visual interpretation using QGIS 2.18.9 (QGIS, 2017), a relatively common technique (Huang et al., 2009; Stow et al., 2007; Vanonckelen et al., 2013), mainly used with high spatial resolution satellite imagery. Polygons were divided in calibration (70%), used as input for the land cover classification, and validation (30%), which was used to evaluate classification accuracy. We used four land cover classes (Forest, Grasses and Shrubs, Water and Bare Soil) to perform classification in the Brazilian Pantanal study areas, and five in anthropic landscapes of São Paulo state (those previously mentioned and a Human class, containing roads and settlements). Prediction maps accuracy was assessed using Kappa's Coefficient (Cohen, 1960) and ranged from 0.776 to 0.997 (mean = 0.933). The analysis was performed using 'RStoolbox' package (Leutner & Horning, 2016) in R environment. A post-classification filter was applied with a 3x3 window size using 'focal' function in R 'raster' package (Hijmans, 2014) to reduce 'salt-and-pepper noise generate by per-pixel classifiers such as Random Forest (Lu & Weng, 2007). The land cover classifications were then visually inspected for misclassifications and corrected when necessary.

Table 1. Land cover classification accuracy assessment. Overall accuracy, Kappa's coefficient and the number of testing polygon by study area are displayed.

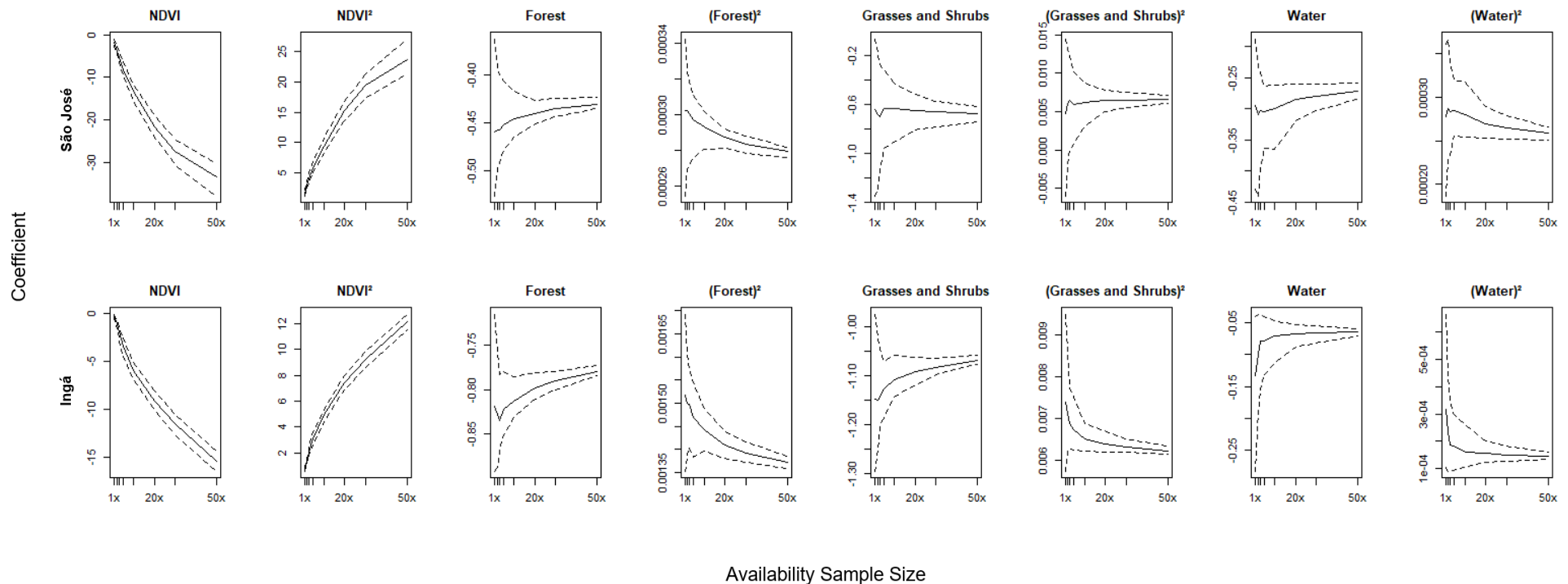
<i>Study Area</i>	<i>Worldview-2 Scene Date</i>	<i>Overall Accuracy</i>	<i>Kappa Coefficient</i>	<i>Testing Polygons</i>
Americana	28 August 2017	0.9504217	0.9359002	187
Araras	14 August 2016	0.9147357	0.8915382	252
Piracicaba	28 August 2017	0.9759063	0.9694975	246
Pirassununga	16 August 2017	0.9873817	0.9839110	210
Ribeirão Preto	09 August 2017	0.9574980	0.9451289	158
São Paulo	06 August 2016	0.8431798	0.7773199	123
Ingá/São Jose	12 March 2017	0.9751002	0.9660237	115
Ipanema	24 November 2016	0.9980065	0.9973420	102
Poconé	01 September 2016	0.9507837	0.9310233	138

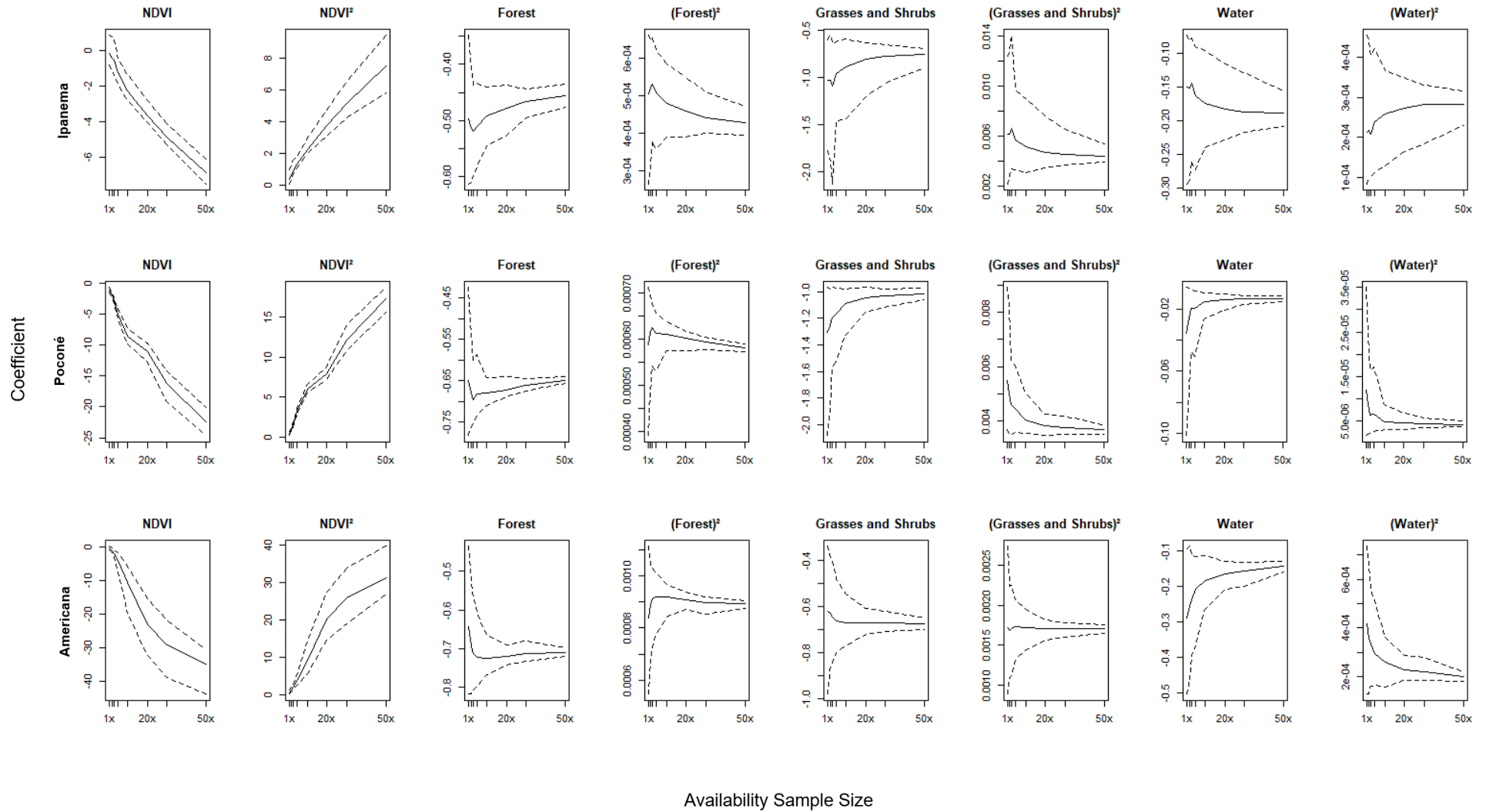
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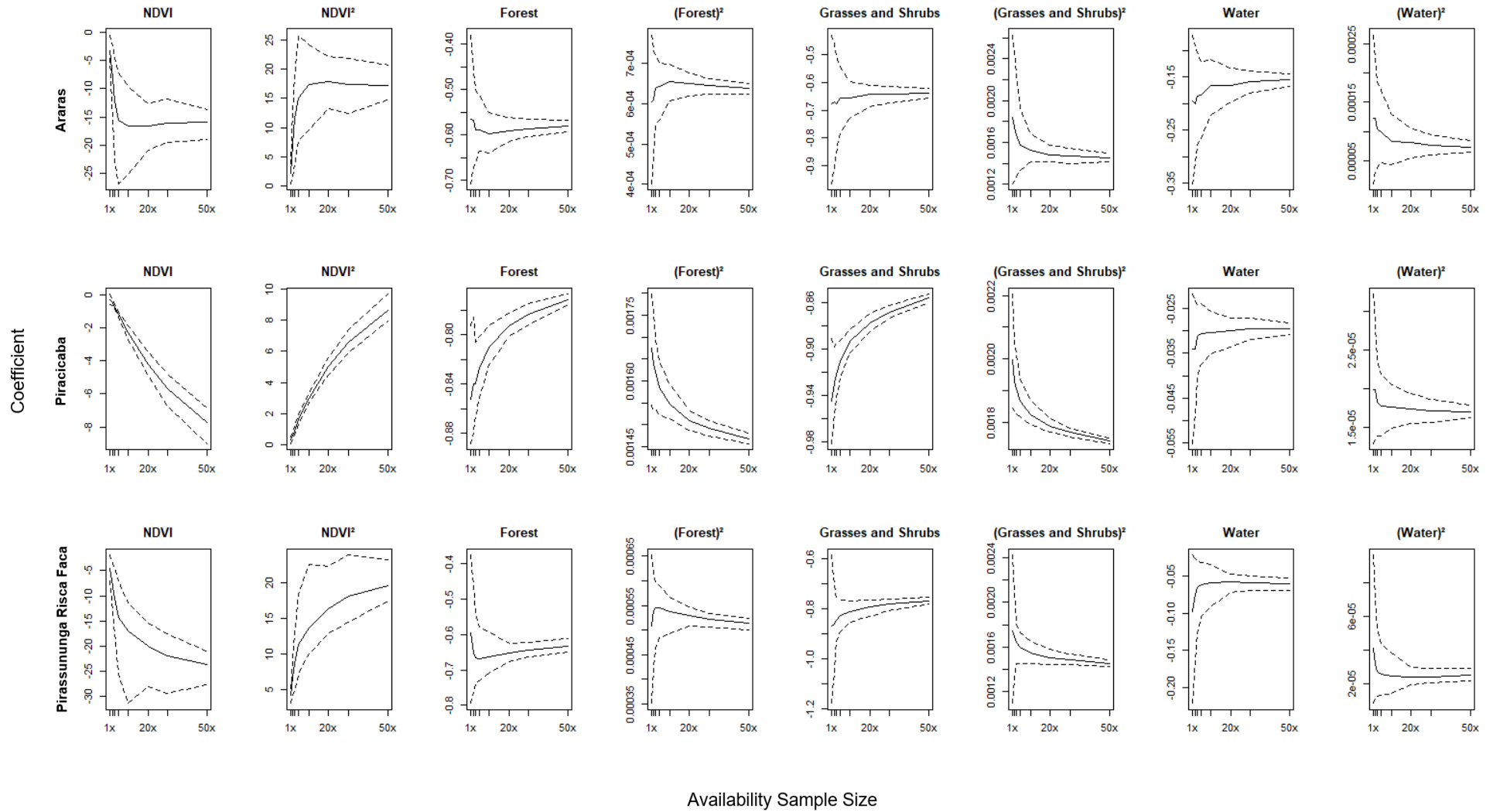
8. APPENDIX 2

Figure 1. Sensitivity Analysis following Northrup (2013). The x axis represents the number of availability points by GPS-location (1, 2, 3, 5, 10, 20, 30 and 50). The y axis provides the generalized linear model coefficients. The graphs are organized in study areas by line and the columns represents the environmental variables tested. In this study we decided to use 30 availability-points by GPS-location.

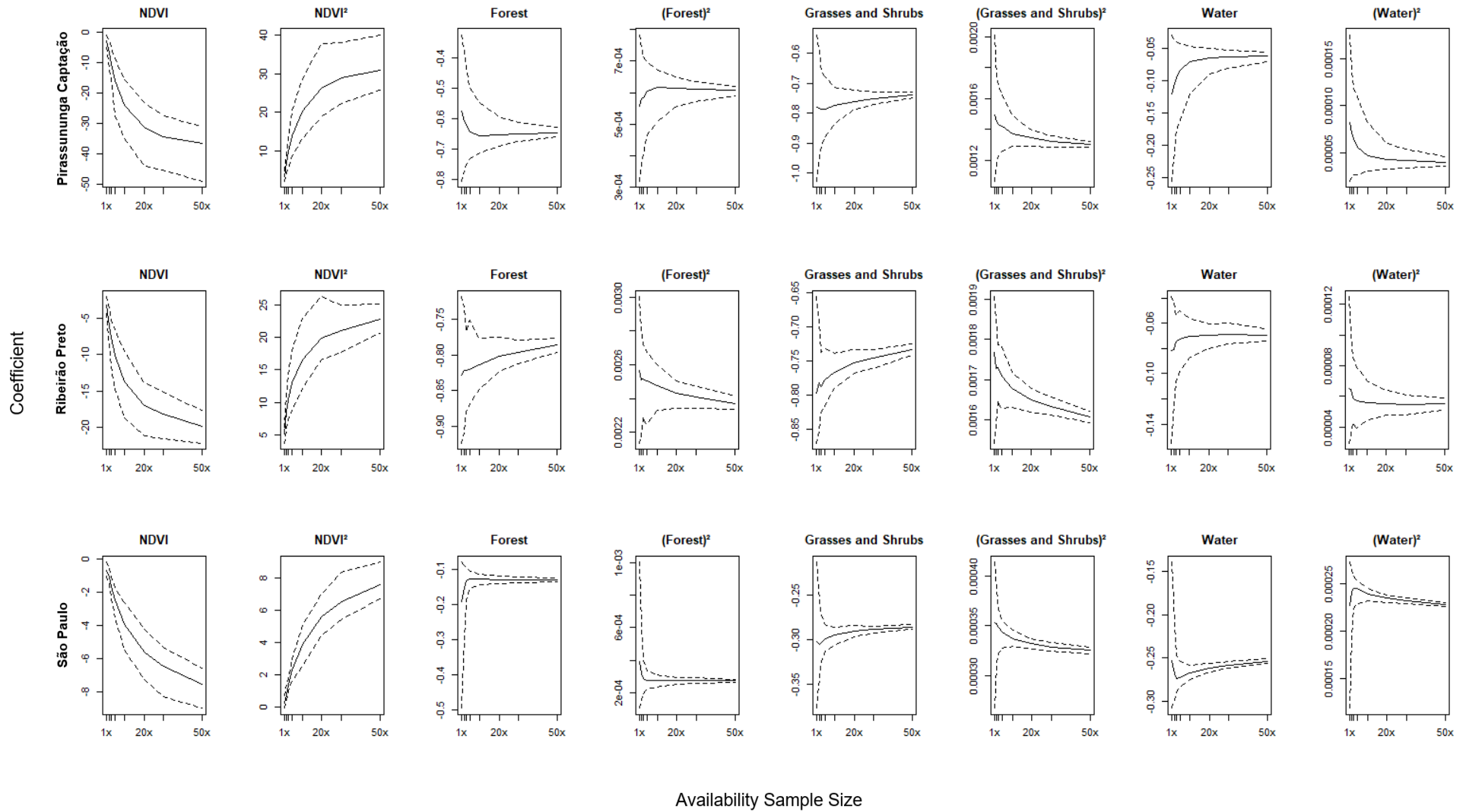




Availability Sample Size



Availability Sample Size



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