Universidade Federal do Rio Grande do Sul

The ecosystem services of the Cerrado trees: modelling, distribution mapping and implications for conservation.

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The ecosystem services of the Cerrado tree communities. Modelling, distribution mapping and implications for conservation.

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Declaration

The work in this masters' thesis is based on research carried out at the Phylogenetic and Functional Ecology Lab, Department of Ecology and Geology, Univ. Federal do Rio Grande do Sul, Brazil. This is an entirely original work unless stated otherwise in the text.

The ecosystem services of the Cerrado tree communities. Modelling, distribution mapping and implications for conservation.

C. Requena-Mesa

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Abstract

The interest in valuing the ecosystem services provided by the natural vegetation has increased in an effort to mitigate the effects of land use change. In this line of thinking, we developed an index to value the tree communities -from an anthropocentric point of view- of the Brazilian savannah (Cerrado). The index and the cartography produced will serve as a tool for prioritization of conservation, has well as to unveil how colonization and agriculture expansion has taken place. In order to develop the index: new environmental layers at 90m resolution were produced; the most common 93 species' distribution was modelled; and cartography for each use humans derive from the trees (food, aromatic, fiber, cosmetic, cork, etc., totaling 20 uses) and a total value index were developed. The new index of value, namely the Sum of Uses (SoU), represent the expected number of uses for the potential species assemblage that could be taking place under optimal conditions. The impact of agriculture was assessed by accounting for the area that has been converted to croplands. Our results strongly indicate that human settlement and cropland expansion have cleared the trees of areas that once were better than average ecosystem service providers. On the other hand, we also observe that protected areas in the Cerrado are located where we expect to find marginal value for the optimal communities. These results lead us to think that the conservation strategy might be far from optimal for the largest remaining arable patch in the world.

Keywords

Brazilian savannah, Ecosystem service, Multi-species distribution modelling, Community value, Conservation prioritization.

Os serviços ecossistêmicos das comunidades de árvores do Cerrado. Modelagem, mapeamento da distribuição e implicações para a conservação.

C. Requena-Mesa

Junho de 2017

Resumo

O interesse em valorizar os serviços ecossistêmicos fornecidos pela vegetação natural aumentou em um esforço para mitigar os efeitos da mudança do uso da terra. Nesta linha de pensamento, desenvolvemos um índice para valorar as comunidades de árvores - do ponto de vista antropocêntrico - da savana brasileira (Cerrado). O índice e a cartografia produzida servirão como ferramenta para a priorização da conservação, bem como para revelar como a colonização e a expansão da agricultura tem ocorrido. Para desenvolver o índice, foram produzidas novas camadas ambientais com resolução de 90m; A distribuição das 93 espécies mais comuns foi modelada; e a cartografia da distribuição de cada uso humano das árvores (alimentos, aromáticos, fibras, cosméticos, cortiça, etc., totalizando 20 usos) e um índice de valor total fo desenvolvido. O novo índice de valor, nomenado a Soma de Usos (SoU, *Sum of Uses*), representa o número esperado de usos para a montagem de espécies potenciais que poderia estar ocorrendo no lugar em condições ideais. O impacto da agricultura foi avaliado pela contabilização da área que foi convertida em lavouras. Nossos resultados indicam fortemente que a colonização humana e a expansão de terras cultivadas eliminaram as árvores de áreas que antes eram melhores prestadores de serviços ambientais. Por outro lado, observamos também que as áreas protegidas no Cerrado estão localizadas onde esperamos encontrar valor marginal para as espécies ótimas. Esses resultados nos levam a pensar que a estratégia de conservação pode estar longe de ser ideal para o maior remanescente arável do mundo.

Palavras Chave

Cerrado, serviço ecossistêmico, Modelado de distribuição Multiespéccies, Valor da communidade, Áreas prioritárias para conservação.

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Introduction

Ecosystem services are defined as “the benefits human populations derive, directly or indirectly, from ecosystem functions” (Costanza et al., 1997). Among all the ecosystem services, the main type arising human interest are the provisioning services, *i.e.*, the services that provide products directly, such as food, raw materials or genetic resources. The interest in price tagging the provisioning services that could be provided by the natural vegetation under a sustainable management has increased in an effort to better manage landscape and mitigate the effects of land use change (Redford & William, 2009; Groot et al., 2010).

The Brazilian savannah (Cerrado) is a vast savannah ecoregion of brazil whose main habitat types include forest savanna, wooded savanna, gramineous savanna, wetlands and gallery forests among others (Vasconcelos, 2010). Land use change together with deforestation are the main threat for the conservation of the Cerrado. In 2005, more than 50% of the total Cerrado area (approximately 2 million square Km) had already been transformed into pasture and agricultural land, mainly planted with cash crops (Klink & Machado, 2005). Deforestation rates have been higher in the Cerrado than in the adjacent Amazon rainforest (Klink & Moreira, 2002), while conservation efforts have been modest: only 2.96% of its area is under legal protection as of 2017. While the expansion of cash crops is prominent (Figure 1), the expansion of protected areas has barely changed since 2005 (2.2% according to Klink & Machado). While the Cerrado is one of the largest remaining arable areas not completely covered with crops in the world, it is also known for being one of the world's biodiversity hotspots and having the richest of floras among the world savannas with more than 7000 species (Klink & Machado, 2005). The duality of being an agriculture lucrative site and an ecologically rich biome, positions the Cerrado as one of the main battleground frontiers for biodiversity conservation worldwide.

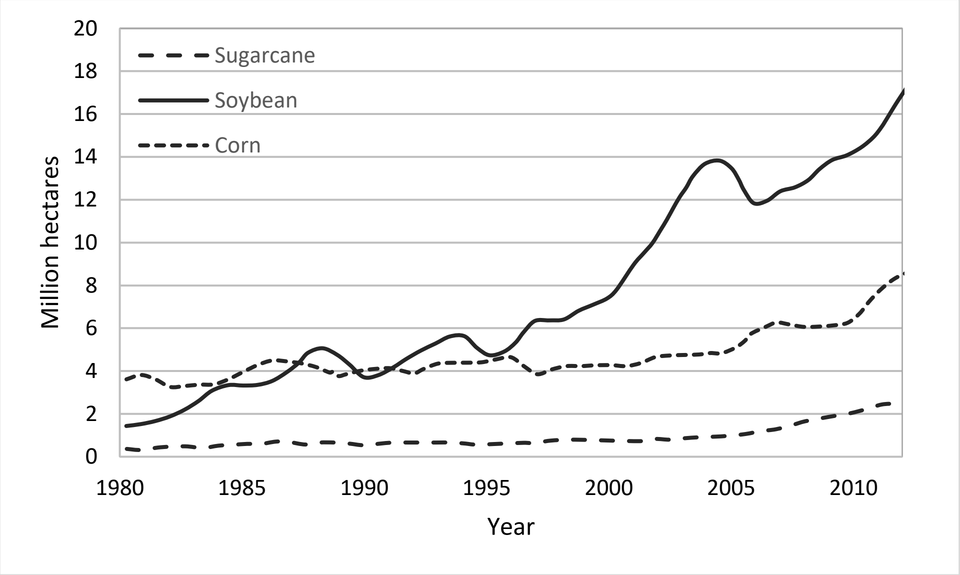


Figure 1. Cash crops cultivated areas trend in some states of the Cerrado.(From: Agribenchmark, calculation based on UNICA 2012 and CONAB 2014).

From the point of view of environmental economics, we can only know how much profit is derived from land conversion to cash crops if we know what is the value that we are giving up by clearing the present cover. Unfortunately, while the trees in the Cerrado are known to have a wide variety of economic viable uses (Embrapa, 2017), the natural vegetation of the Cerrado mostly remain classified as having no economic value.

There are several ways that mapping the distribution of the uses can help the conservation of the Cerrado. First, by providing locals with a tool to find and make use of possible 'ecosystem service hotspots', improving farming practices while enforcing sustainable use of these newly characterized services. Second, by providing managers with information to better prioritize conservation while being able to get some profit from the ecosystems, *i.e.*, by making protected and managed areas more lucrative and of larger size thanks to the income that a sustainable use of its resources would bring. And ideally, under a good price tagging effort, by making the profit of these services more valuable for land owners than a conversion into cash crops under certain scenarios. This last point can only be a reality if cash crops decrease in valuable over the next decades; however, that is not clear to be the case (Irwin & Good, 2015).

The first objective of the present work is to develop a descriptive tool (database) of the Cerrado tree uses distribution that can help to improve prioritization strategies and to better understand the system. This objective will be reached after covering the aspects listed below:

i. To model the **distribution of the main tree species** for the Cerrado at a fine grain.
ii. To **test the modeling for validation** comparing the prediction to observations in previous field work.
iii. To develop an index expressing '**potential value of provisioning services**' to compare the potentiality of different areas.
iv. To develop an index of '**real value of provisioning services'** given actual tree cover.
v. To **estimate the impact** of agriculture in the total available value of provisioning services up to present day.

In addition to point out and map the density distribution of the provisioning services derived from the tree communities in the present work, we intended to unveil how the Cerrado was colonized and how much of its original value has already been lost. In order to achieve so, we will make use of the generated distribution of provisioning services provided by the potential tree communities (produced in the third step of the first objective), *i.e.*, the tree species that would occur under ideal circumstances (no human intervention and 100% tree cover).

We hypothesize that areas where population and agriculture have already been established are those that could potentially offer more provisioning services than average. It is natural to think that tree species that offer a good amount of provisioning services will likely not take place in extreme environments; but in those sites with good water availability, low slope, good temperature range, etc., which in turn happens to be ideal for agriculture and population establishment. We expect to find higher potential value (in terms of provisioning services) of the natural vegetation in those areas that have already been occupied by cities and agriculture.

If our first hypothesis is true -human activities and ecosystem service rich communities occur in the same places-, it is also very likely that the next statement will be true too: in protected areas, natural vegetation has a lower provisioning services value than average. Protected areas in the Cerrado were established sometime after population settled and main transportation routes were laid down, *i.e.*, mostly in areas were human activities had not reached yet. It is to expect that human was not using those areas since the land had a lower potentiality for economic development, *e.g.*, maybe high slopes or no water availability, and therefore ecosystem services provided there might be also lower than average.

As a summary, the second objective of the present study is to test whether the following hypothesis are true:

i. Human activities (population settlement and agriculture) mostly take place where we would expect to find higher than average value of ecosystem services.
ii. Protected areas, on the contrary, are established in landscapes where marginal ecosystem service value is expected to be found.

Materials and Methods

An incremental approach was used in order to model the distribution of the provisioning ecosystem services offered by the potential tree communities. First, we modelled the environmental predictor variables for the study area at a better grain size than available. We then proceeded by modelling the distribution of the most common tree species in the Cerrado (SDM), whose human derived uses are known to us. We then computed and projected the community weighted means for each of the uses. To finish we developed a basic index to have a rough estimation to the total value (from an ecosystem service perspective) of the potential communities. The resulting index express the ubiquity of ecosystem services in the tree communities that can potentially inhabit the area.

Since our metric for ‘potential tree communities’ is the simple sum of all the tree species that could potentially inhabit a site, it seems reasonable to not call it ‘community’, but ‘species assemblage’ since our floristic composition would not be representative of a real community .

2.1. Study Area

The study area comprehends the contiguous Brazilian Cerrado (Figure 2), totalling an area of 2,203 thousand Km^2. We did not focus on the small patches of savannah that lie far from the main continuous ecosystem (some of which are north of the amazon). This decision is due to the inaccuracy that including those small areas would introduce into the modelling process, since environmental factors and community composition vary greatly among them, in part, due to the influence of other surrounding biomes. The sampling units that were used as our training set for the species distribution modelling are marked on Figure 2. The training set was first collected and analysed on Ratter et al. 2003, where a detailed explanation on sampling methodology can be found. Our training set is, in fact, a bit denser that the one described in Ratted et al. 2003, since the research group continued collecting new units after the original publication.

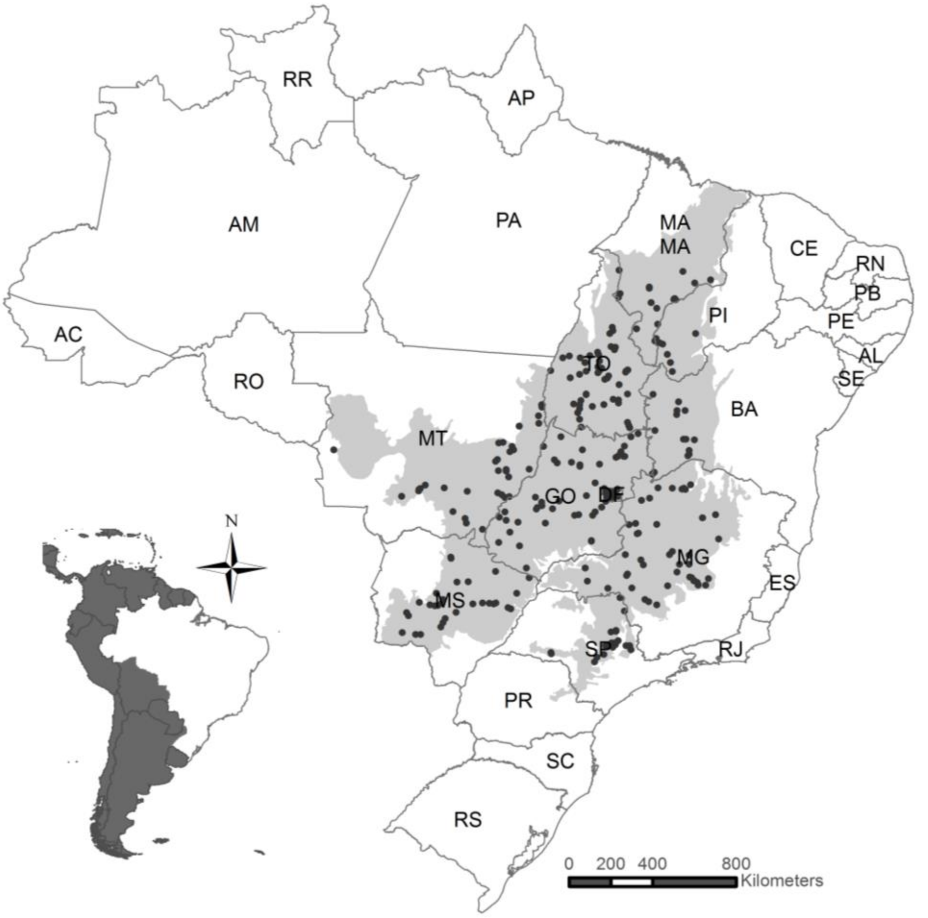


Figure 2. Study Area in grey, the contiguous Brazilian Cerrado. Points represent the 312 sampled locations for tree species presences and absences.

2.2. Modelling and selection of predictor variables.

The highest resolution environmental information freely available for Brazil is rarely finer than 1 km grid. Such coarse data does not satisfy the needs of our first objective: to develop a tool useful in site, that does represent the real vegetation expected. This decision is better understood with an example: one square kilometre is big enough to fit inside a valley and a mountain side (or even a whole small mountain). The value for that pixel will resemble somehow the average value for the whole square kilometer; however, due to the heterogeneity, in a finer grain observation, that same value might not be observed at all in the area. As example, we might think the slope is zero, but in a finer grain we might find a very rough terrain with many small slopes higher than zero.

We base our environmental modelling on the freely available digital elevation model STRM v4 (Jarvis et al. 2008). Although, computationally costly for such a large area, we decided to maintain a 90m pixel side resolution for all of our models, since it will best satisfy our needs. In case a coarser grain is needed in order to compare to other projections or to test hypothesis, up-scaling can be performed without information loss. Furthermore, tree cover (%) is known in the Cerrado at 30m resolution and, by making use of this information, we can compute ecosystem service density as one of the final products of our modelling at a very fine grain. The generated climate models, and subsequent products can be of great use for future Cerrado studies, please contact main author to access the data.

2.2.1. Terrain predictors

The terrain predictors to be used are those that can be obtained by direct computation on the digital elevation model (STRM v4, Figure 3.a). The slope (first derivative of altitude, Figure 3.b) and curvature (second derivative, 3.c) were computed, as this information can be useful for explaining the distribution of the species. In addition, an aspect layer, *i.e.*, the orientation that the slope is facing towards, was also generated (Figure 3.d).

Since ground water availability is known to be a key factor for the development of communities in the Cerrado and tree species can be very specialized at reaching the water table with their roots, a water table influence layer (Figure 3.e) seems of vital importance for the species distribution modelling (SDM). Since there are no guidelines on how to model water table in absence of piezometric level measurements, a relation to the proximity of water courses was modeled establishing the slope as the rugosity, and taking into account the water flow of the streams, *i.e.*, their rank. In order to do so, we first computed a flow accumulation raster, *i.e.*, a raster expressing how many cells are uphill of each cell. Based on that raster, we were able to generate a river network in a very fine grain: rank 1 streams were set to be those with at least 1 Km^2 of upstream area. Horton-Strahler ordering was used to rank the rest of the streams (being rank 9 the highest found in the Cerrado). For each of the ranks, a cost-distance raster was computed, the slope (Fig 3.b) was used as the rugosity, in such way that a cell will only have a high influence of the water table if it is close to the stream or if there are not high slopes in the way. Each rank's influence was them multiplied by its correspondent value in the Fibonacci series, since higher rank rivers are expected to be able to influence a higher area around them.

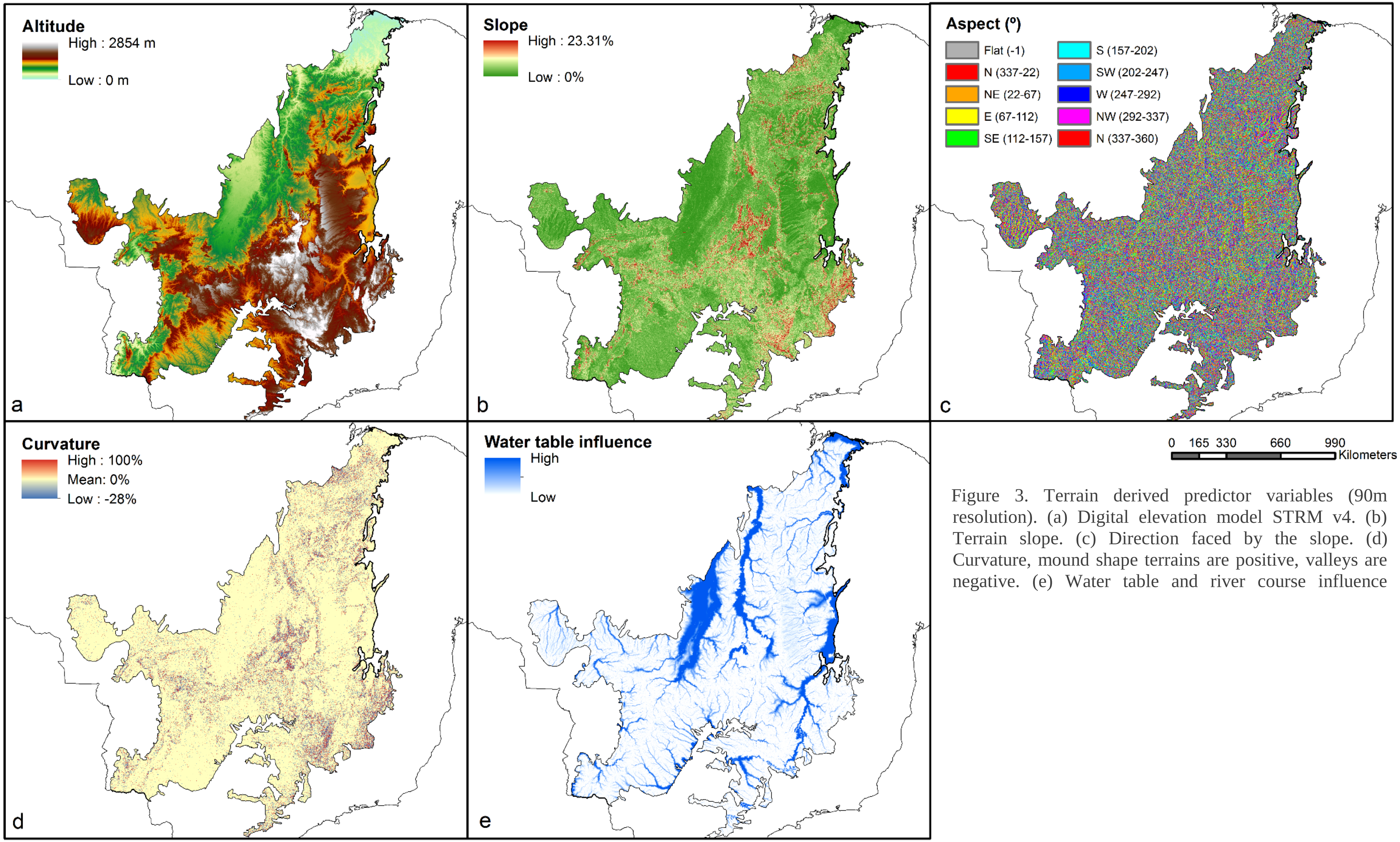


Figure 3. Terrain derived predictor variables (90m resolution). (a) Digital elevation model STRM v4. (b) Terrain slope. (c) Direction faced by the slope. (d) Curvature, mound shape terrains are positive, valleys are negative. (e) Water table and river course influence

2.2.2. Climatic predictors

Climatic variables were predicted over the study area by training a linear model on long term records of the Brazilian Meteorological Institute (INMET) available at the database BDMEP (Figure 4). All the weather stations with at least 30 years of records and located in the Cerrado and those surrounding it were used, totaling 146 stations. The data was cleaned and corrected for gaps. Linear models were trained for each of the climatic variables using as input features solely Altitude, Latitude and Longitude for the temperature layer. Later, temperature, together with the previous mentioned features was used to model more complex variables such as relative humidity or potential evapotranspiration. Residual analysis was performed for every trained model in order to check that the model selected fits the data correctly. In order to project the predicted values over the study area, the residuals were first laid down in their correspondent coordinates and Ordinal Kriging interpolation was used to account for unexplained variance. Interpolated residuals were summed to the model's predicted values, by using this technique, we also account for all the microclimatic differences that can exists throughout the study area that the models did not account for.

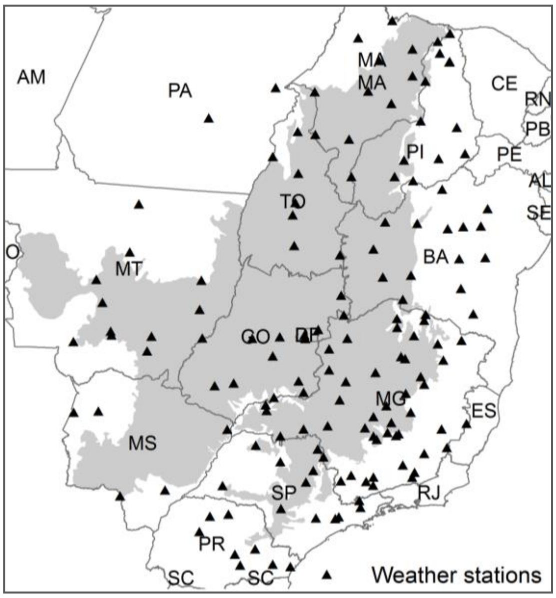
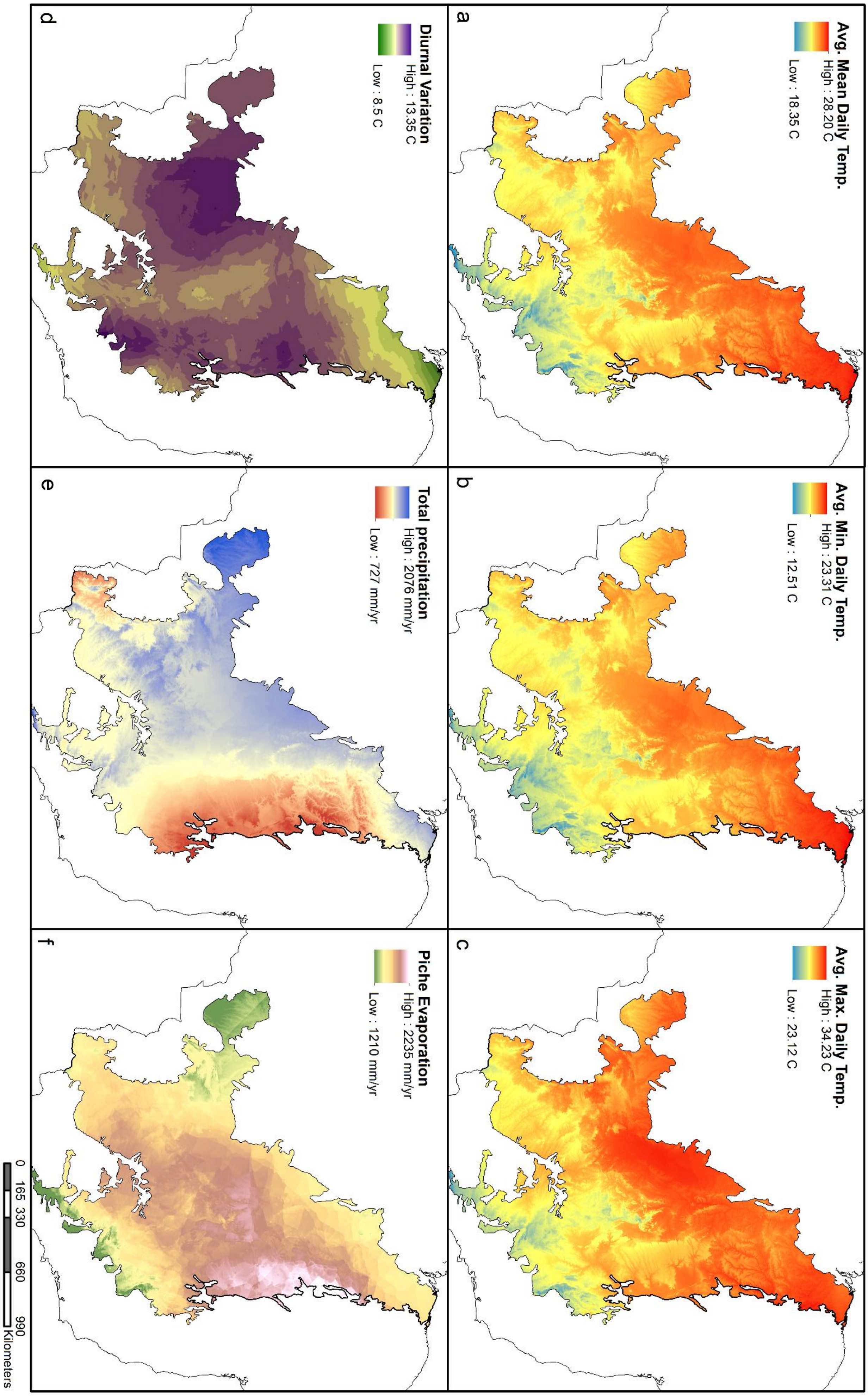


Figure 4. All 146 INMET weather stations used for climate modeling.

There is no INMET weather stations in the east of Mato Grosso (MT) and it was not possible either to get any data from the Bolivian side of the border. Therefore, the climatic variables of the small patch of Cerrado bordering Bolivia are extrapolated from those known. The fitted models' parameters are on Appendix B. We must not forget that all of the variance that is not accounted for by the models, is later introduced by Ordinal Kriging; therefore, a poor

R-squared does not necessarily means that the prediction will be far off from the observed. However, it will be less detailed, since the importance of interpolation will be greater and interpolation does not offer detailing at small scales. This effect can be observed on the wind speed projection (Fig 4.i). Ten of the twelve climatic variables can be previewed on Figure 4-a~j.


a
Avg. Mean Daily Temp.
High : 28.20 C
Low : 18.35 C
b
Avg. Min. Daily Temp.
High : 23.31 C
Low : 12.51 C
c
Avg. Max. Daily Temp.
High : 34.23 C
Low : 23.12 C
d
Diurnal Variation
High : 13.35 C
Low : 8.5 C
e
Total precipitation
High : 2076 mm/yr
Low : 727 mm/yr
f
Piche Evaporation
High : 2235 mm/yr
Low : 1210 mm/yr
0 165 330 660 990
Kilometers

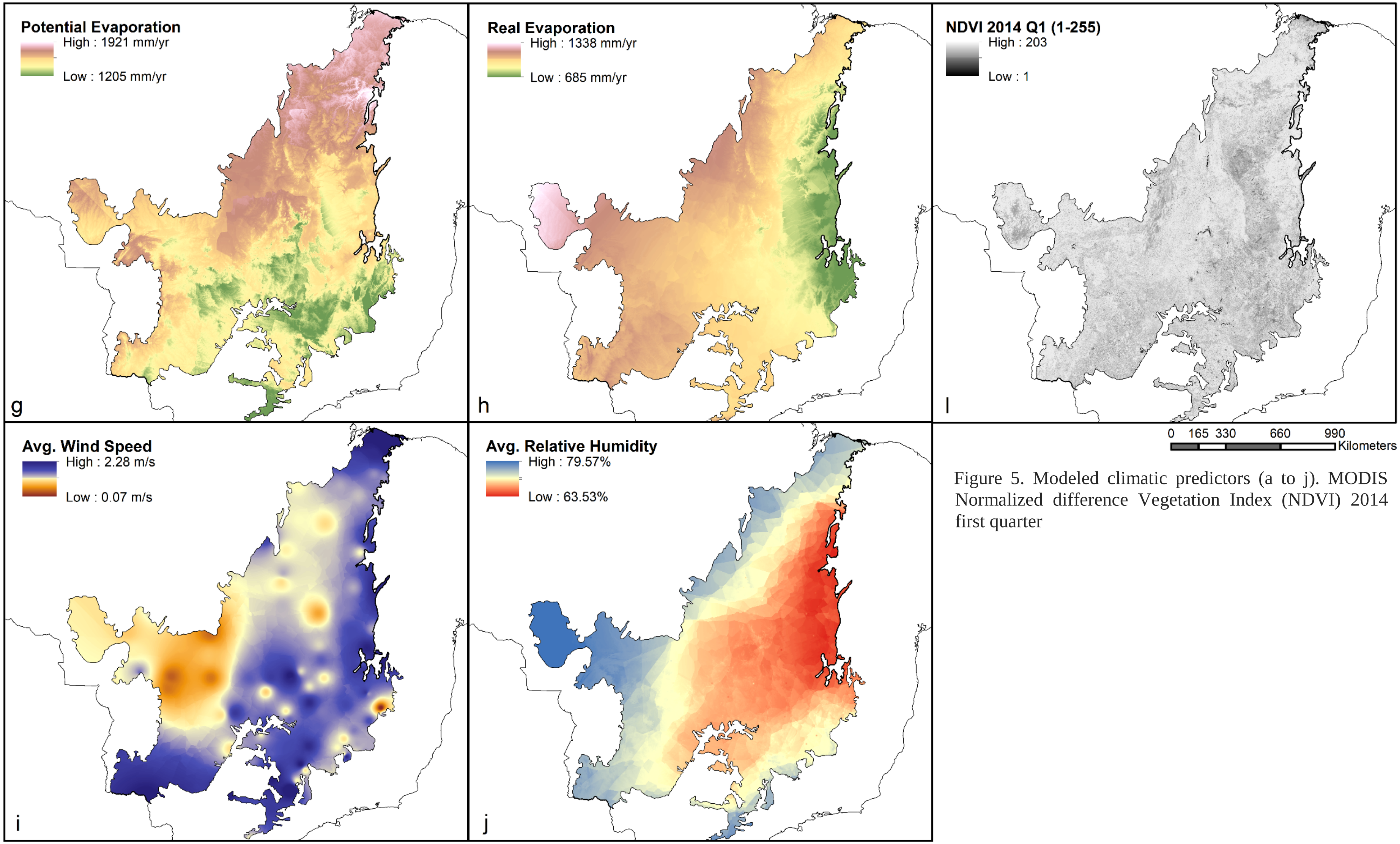


Figure 5. Modeled climatic predictors (a to j). MODIS Normalized difference Vegetation Index (NDVI) 2014 first quarter

2.2.3. Edaphic predictors

Soil information available from ISRIC's Brazilian SOTWIS information layers was used to map the soil units. Soil variables were assigned to each soil polygon unit and rasterized at 90m. The original resolution of SOTWIS Brazil is far coarser than that we implemented and thus, we are committing a great amount of interpolation and missing details at our aim resolution. However, this is to our knowledge the best freely available way to take into account edaphic predictors in the SDM, and the lack of certainty at a fine grain can be compensated by an overall greater accuracy.

The soil variables were computed only for the first 0-20 cm of soil, these are: coarse fragments mass (%), sand (%), silt (%), clay (%), bulk density (kg dm^{-3}), available water capacity (cm m^{-1}), cation exchange capacity, base saturation, pH measured on water, total carbonate equivalent, gypsium content, electrical conductivity, organic carbon content, total nitrogen and effective cation exchange capacity.

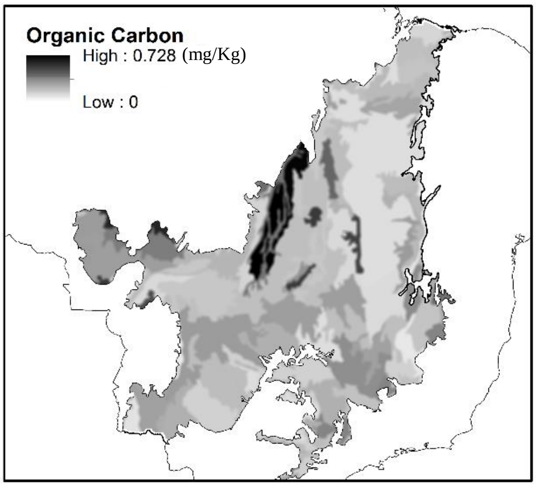


Figure 6. Sample edaphic predictor. Total organic carbon content (mg/Kg) for the 0-20cm soil layer.

2.2.1. Selection of predictors

Based on the potential advantages found by Amaral et al. 2007 of including greenness indices as predictor variables, four NDVI predictors were also included accounting for each of the quarters of the year 2014 (Figure 4-l).

In order to avoid undesired co-linearity in the input features that can produce artifacts during the SDM, we selected only those predictors not correlated. Edaphic predictors were ordinated via PCA, those predictors with the highest weights in the first three components were chosen to be used for the SDM. For terrain, climatic and NDVI, only one of the predictors showing high correlation was selected based on a threshold criterion of 0.8 in Pearson correlation test. The 20 predictors used for the species distribution modeling are listed below

Table 1. Predictor variables used for the Species Distribution Modeling (SDM).ECEC: effective Cation Exchange Capacity. CECS: Cation Exchange Capacity of fine earth fraction. PHAQ: pH measured in water. TAWC: total available water capacity.

Terrain	**Climatic**		**Edaphic**		**Greenness**
Altitude	Average Temp.	Precipitation	ECEC	CECS	NDVI Q1
Slope	Rel. Humidity	Wind Speed	TAWC	PHAQ	NDVI Q3
Aspect	Real Evap.	Diurnal Va.	Total Carbon		
Water table	Potential Evap.	Piche Evap.	Sand (% mass)		

2.3. Multi-Species Distribution Modelling

Species distribution modelling is the cornerstone of the project. We modelled the probability of presence in the 90m grid for the 93 most common tree species based on the 312 sampled locations (Fig. 1) using Biomod2 (Thuiller et al., 2014) for R (See Appendix F for tree species detected overview and Appendix E for an exhaustive list of species modelled). Only species with at least 7 detected presences were modelled. Our observations account for real absences (Ratter et al. 2003), and so the fitness of the models can be easily measured based on True Skill Statistics (TSS) or the area under the curve (AUC) of the receiver operating characteristic curve (Jiménez-Valverde, 2012). In order to do so, we first needed to partition at random our samples into two sets (80% to 20%): one for training the algorithms and another one for testing the accuracy and validate the model. The partitioning was performed 3 times, *i.e.*, the fitting of every algorithm was run 3 times, each of them with a slightly different training set selected at random.

Five different algorithms were fitted to each training set, namely General Linear Models (GLM), General Additive Models (GAM), Random Forest (RF), Artificial Neural Networks (ANN) and Generalised Boosting Model (GBM). The TSS was computed for each algorithm by comparing the predictions generated to the testing set (observations that were not previously fed during training). Since the algorithm training had to be performed for 93 species in a row, an expert selection of best explaining models could not be used. Instead, an automatic selection (dynamic threshold) of the best explaining models was chosen. Models were ordered by their ability to predict the testing set (TSS), and only those with better than median TSS were used to generate a consensus model. The consensus models are a weighted mean of those algorithms with TSS higher than the threshold; TSS values were also used as the weights for the mean computation. A total consensus of the 3 runs was later computed by simple arithmetic mean of the 3 resulting projections, a sample total consensus projection for *Dypterix alata* can be seen on Appendix C.

2.4. Species Assemblages

The objective is to estimate the prevalence of each of the uses human derive from the trees in the species assemblage (our measure of 'potential tree community') based on the distribution of the species we have modelled. Using information collected by Embrapa (2017) we know what ecosystem services are offered by each tree species. These twenty provisioning services are namely: alimentary use, handcraft use, aromatic, cork, condiment, cosmetic, forage, fiber, latex, timber, medicinal, melliferous, oleaginous, ornamental, resin, repellent, tannic and dyeing. Uses were treated as traits for each of the species (they can be present or not in a given species), and the community weighted mean was computed for all the 20 uses using SYNCSA (Debastiani & Pillar, 2012) and later projected into a 90m two-dimensional grid. An example layout of potential use distribution can be seen in Appendix D. Computation is summarized in the equation below.

$$Prev_{(x,y)} = \frac{\sum_{i=1}^{93} P_{i(x,y)} * S_i}{\sum_{i=1}^{93} P_{i(x,y)}}$$

Where ‘Prev’ is the prevalence of a given use (from 0 to 1), P is the probability of presence of species i in location (x,y) and S is the occurrence of the use in species i.(0 if absent and 1 if present). For easier understanding on how the previous equation is applied, we can practice on a hypothetical community with only 4 species:

Species	*Prob. of presence*	*Food use*
A	*0.05*	*1*
B	*0.75*	*0*
C	*0.5*	*1*
D	*0.95*	*1*

In the above community, the prevalence of the food use would be computed as follows:

$$Prev = \frac{0.05 * 1 + 0.75 * 0 + 0.5 * 1 + 0.95 * 1}{0.05 + 0.75 + 0.5 + 0.95} = 0.56$$

Since the ecosystem services’ prevalence has been computed as a weighted mean, the possible high uncertainty of some the species’ distribution was reduced; when averaging 93 values with wide confidence intervals, the resulting average will have a much smaller confidence interval. Therefore, we believe the computation used is in the safe side and we can be confident on the projected distribution of ecosystem services.

In order to develop a summary index, each of the uses was normalized via min-max scaling, and all of them summed to create a total ecosystem value index, namely Sum of Uses (SoU):

$$SoU_{(x,y)} = Tree\ Cover_{(x,y)} * \sum_{i=1}^{20} \frac{Prev_{i(x,y)} - \min(Prev_i)}{\max(Prev_i) - \min(Prev_i)}$$

Where ‘Prev’ is the prevalence of a given use (i), out of the 20 studied uses. For potential SoU we assume tree cover to be 1 for every (x,y).

The new index (SoU) will serve to compare the value, from an anthropocentric point of view, of the different assemblages in the Cerrado. However, it will not serve to compare the value of the Cerrado to that of other biomes, since it is not an absolute measure. The index ranges from 0 (no service value) to 20 (maximum hypothetical value). The interpretation of the index is quite easy, a value of 20 means that all of the species in the assemblage have all of the possible uses (and tree cover is 100%). A value of 10, can mean an infinite combination such as the following: all of the species have just 10 uses; half of the species have all of the uses and the other half have none; all of the species have all of the uses but tree cover is just 50%. Possibilities are endless, so the index cannot be interpreted at a low level. The developed index has a potential to be directly related to monetary value ($) per area. This relation could be established in a future study. A simple sum of the uses was selected over other possible indices. Summing the prevalence of the services assumes that all of the uses are equally important (and this is possible far from reality), however it would be a great source of bias to try to estimate what resources are more valuable (what could we base our assumptions on?). What is valuable today for humans might be vestigial in a couple of years. The simple sum of use (SoU) will allow us to compare the different species assemblages without introducing a new source of bias.

2.5. Cerrado colonization (Hypothesis testing)

In order to check if human activities have cleared out parts of the Cerrado that are more valuable than average we can compare the value of the species assemblages under three different negative and positive pressures: agriculture, human density and protected areas. Our model of the Cerrado has 600 million pixels, however we do have 600 million degrees of freedoms, our data is likely to have a high autocorrelation, *i.e.*, points that lie close to each other are likely to not be independent observations. Mean comparison, as well as most parametric tests, do require independent observations to function correctly.

Autocorrelation of SoU was checked by plotting the correlogram based on Moran’s I (Figure 7).

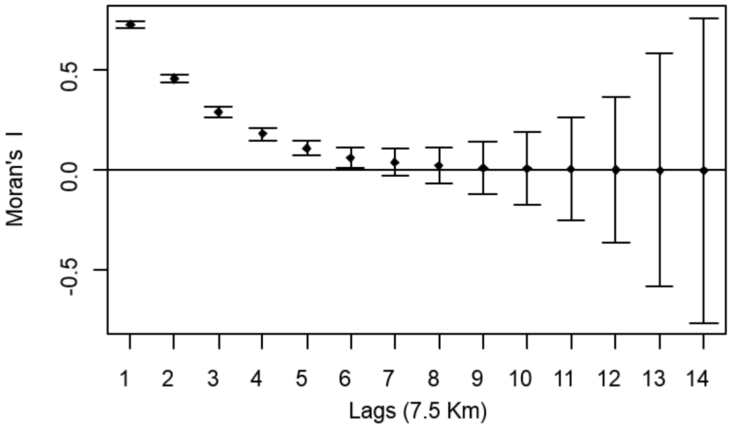


Figure 7. Moran's I correlogram of the Sum of Uses Index. Positive spatial autocorrelation extends to the 7th lag (52.5km).

Positive autocorrelation extends to 52.5 km (roughly 0.45 degrees), from where the effect of autocorrelation cannot be appreciated significantly (dropping to clearly zero at 67.5km). Since there is no negative autocorrelation, the farther two points are, the less correlated they will be. We can safely assume that in the study area there is only place for approximately 572 independent SoU observations that lie 750 pixels apart of each other. Sampling from the Sum of Uses (SoU) layer was performed as a floating pseudo-random Gaussian grid with approximately 572 points. Points were distributed in a semi-grid at random, following a normal distribution, so they were 67.5 ± 6.75(s.d) km apart of their closets neighbor (roughly 0.6 degrees), which guaranties the independence of observations (See Appendix A for illustration). 5000 iterations of bootstrap resampling procedure were performed.

Human populated areas were defined as those with at least 10 inhabitants per square kilometers based on WorldPop (Andre J., 2017). Agricultural areas were gathered from MODIS 500m measured on the period 2001-2010 (Broxton et al., 2014). Data on demarcation of protected sites was used from ICMbio.

2.6. Impact assessment

Real species assemblages' value (Real SoU), a valuable tool for prioritization, was computed by accounting for real tree cover (Hansen et al. 2013). Agriculture extension was derived from MODIS 500m data for the period 2001-2010 (this is, as of now, outdated information due to the rapid increase on crop land uses) as seen in Broxton et al., 2014. We estimated the total value lost by agriculture expansion by assuming that tree cover in those areas that now are croplands used to be the same as those remaining. Same methodology was used to assess the value impacted by built-up environments (cities and roads). This method is, of course, subject to high uncertainty, since we cannot know what the tree cover used to be before the vegetation was cleared. However, it serves to have a rough estimate of the ecosystem value (%) lost to agriculture and city expansion.

Results

3.1. Tools for research and prioritization

Climatic model's goodness of fit parameters can be seen on Appendix B. Since all the available data was used for training as a mean to get the most accurate models, none of it was left for validation. It is in fact, not our intention to measure the accuracy of the environmental models themselves, but to measure the accuracy of the species distributions that were modeled based on these environmental factors. Due to the use of interpolation and sum of the residuals to the predicted values we can be certain that our environmental models do predict the right absolute value throughout the Cerrado, and the produced predicts can be potentially useful for future studies in the Cerrado.

When comparing the distribution generated for all species to the distribution found *in situ* (our validation set) the area under the curve (AUC) of the ROC is 0.74 ± 0.13(s.d), while TSS values are 0.52±0.19 (s.d). To which extent these metrics indicate that models are good remains a matter of subjectivity (Arujo et al., 2006; Jiménez-Valverde et al., 2008), both metrics indicate that our prediction is half way between random and perfect. Measuring the fitness of a model by comparing its prediction to new observations is harsh, and in fact, a test that is not widely performed in most ecological studies due to its righteousness. The observed accuracy of the models is, for some of the species, below of that of most published SDM studies; however, for most of the widely common species the accuracy is just as good as seen in most studies (Marion et al., 2009; Svenning et al., 2008). According to Elith (2002), models with AUC values above 0.75 are considered potentially useful. We believe the measured accuracy is good enough to fulfill our first objective (develop useful tools for prioritization), taking into account that it was to expect deviations at such fine grain, under such large and heterogeneous area, and modelling such large number of species.

Distribution of the individual ecosystem services, as a tool to locate natural resources and prioritization of conservation, was laid out for the 20 examined uses. A sample layout can be seen on Appendix D (the remaining 19 uses are attached to the text as an electronic resource). The accuracy of the modeled distribution of ecosystem services rely on the accuracy of the SDM; the confidence on the generated distribution of uses is higher than the confidence on the prediction of individual species due to the averaging over a large amount of species.

Potential value as Sum of Uses (SoU) was mapped for the Cerrado (Figure 8). The value of the index approximates the expected total value across all provisioning ecosystem services derived from trees on the potential natural communities; *i.e.*, the value of the services under ideal circumstances (no human impact, total tree cover and no species interspecific relations). From the potential SoU was derived the realized sum of uses (Real SoU), by taking into account real tree cover. The realized Sum of Uses (Real SoU) represent the value of ecosystem services under nowadays circumstances (See Figure 9) and is regarded as the main tool from this study for future conservation planning.

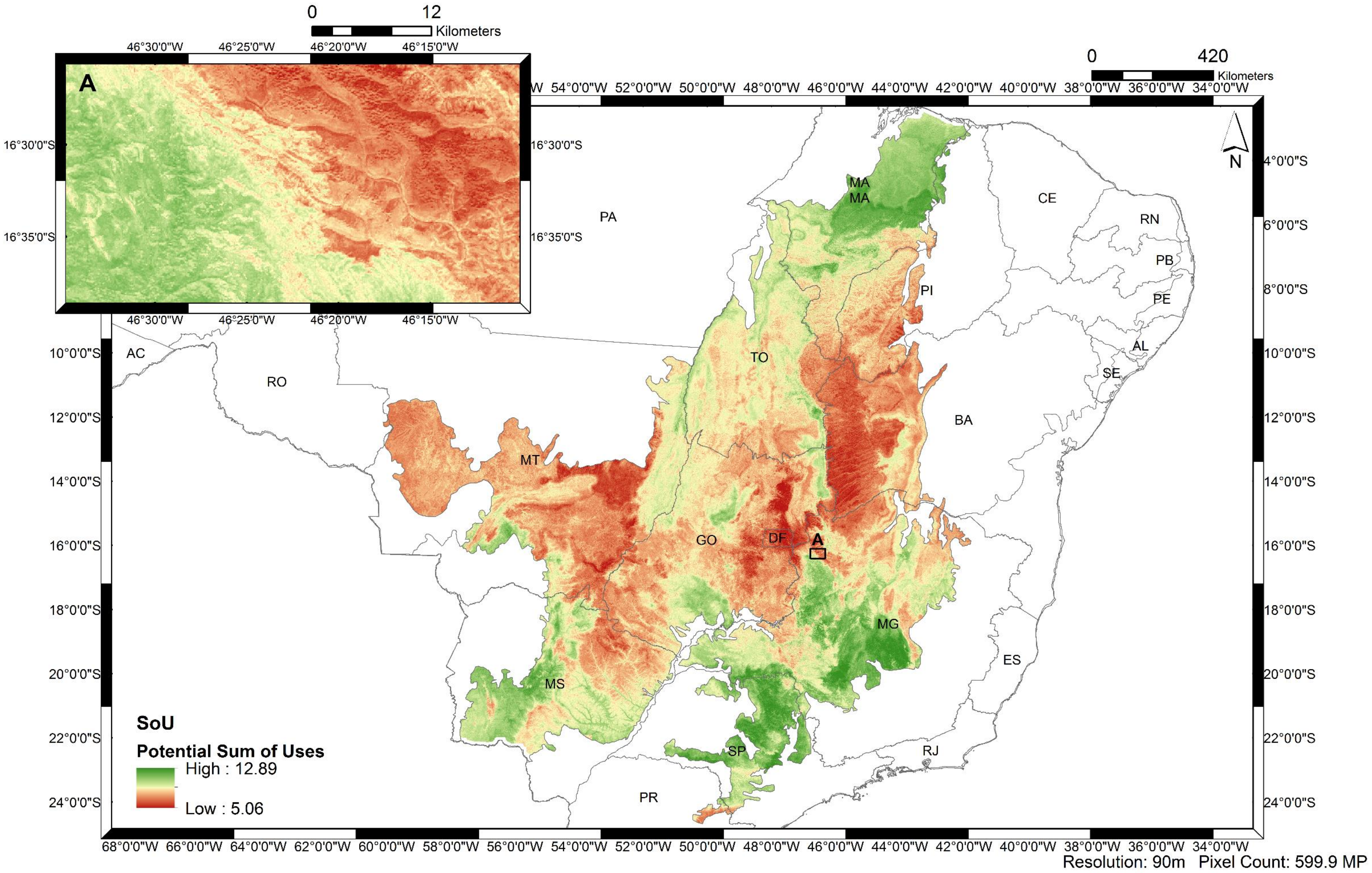


Figure 8. Distribution of provisioninge ecosystem services of the potential tree assemblages (if tree cover were 100% everywhere) for the Brazilian Cerrado.

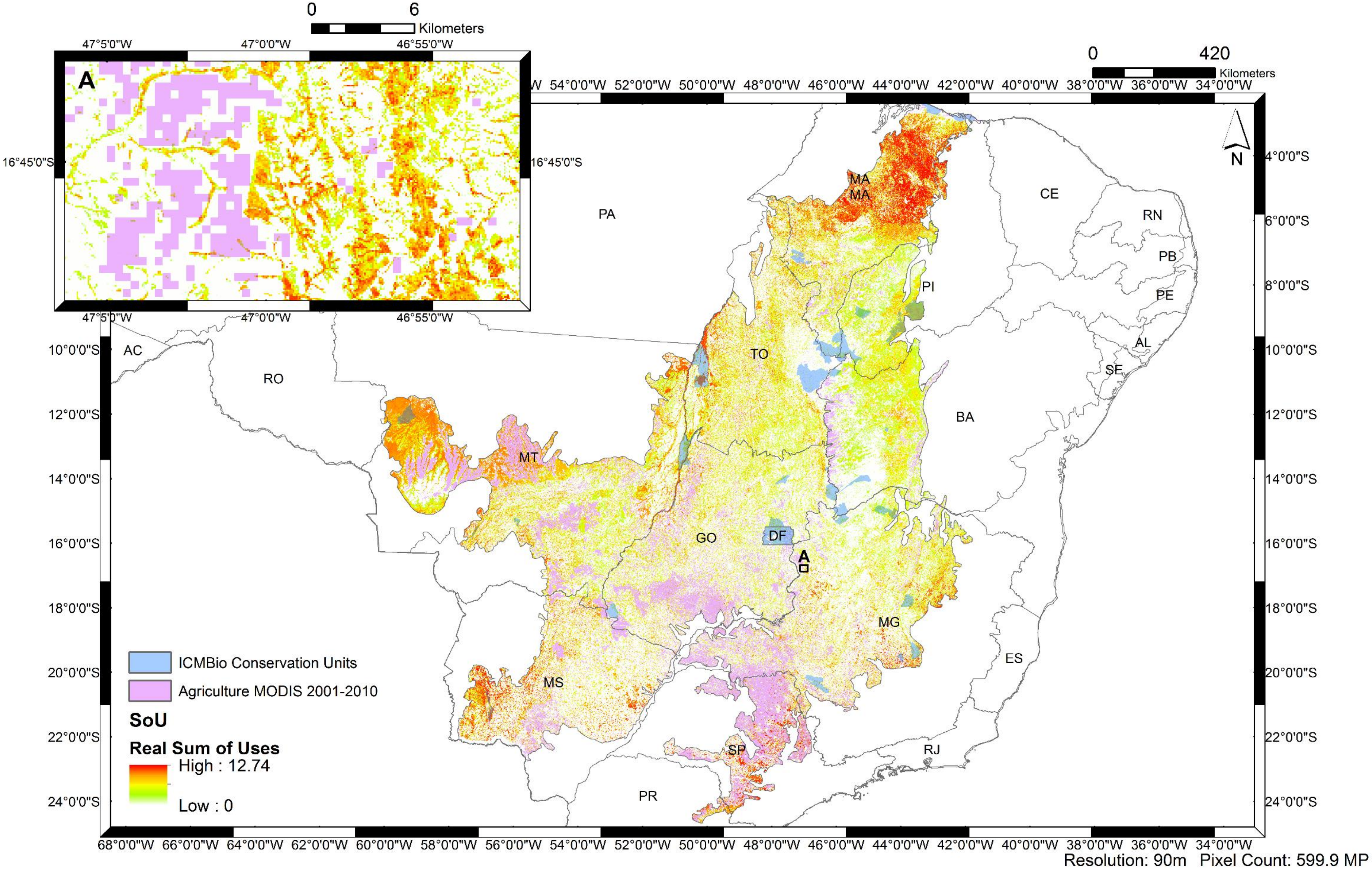


Figure 9. Distribution of provisioning ecosystem services of the real tree cover for the Brazilian Cerrado. Overlaid are, agriculture land used derived by MODIS 500m in pink (Broxton et al., 2014) and conservation area sin blue

3.2. Distribution of human induced impact

The minimum value of SoU found in the Cerrado was 5.06 uses and the maximum 12.89 uses. The areas where agricultural systems are established have an average potential SoU that is 0.23 uses (± 0.11 standard deviation) higher than average ($p = 0.0178$), meaning that agriculture has preferentially cleared patches of Cerrado that could potentially offer a higher amount of provisioning services. Although this difference is statistically significant, the magnitude of the estimated difference in SoU (0.23 uses) might not be of special importance considering that the total range of SoU in the Cerrado is 7.83 uses.

There is also evidence that human population is occupying areas where tree uses prevalence in the predicted species assemblages is 0.963 ± 0.07(s.d) uses higher than average for the Cerrado ($p<0.001$). Unlike for agriculture, the magnitude of the estimated difference seems relevant: it means that built-up environments are clearly taking the place where provisioning services would have a greater value.

In integral protected areas, we observe 0.66 ± 0.23 (s.d) units of SoU less than expected ($p= 0.0014$)., meaning that protected areas are, in fact, marginal land for ecosystem services derived from trees when compared to those areas that are not protected. See Figure 9 for a better picture of the SoU differences found among the spatially independent subsamples of potential SoU.

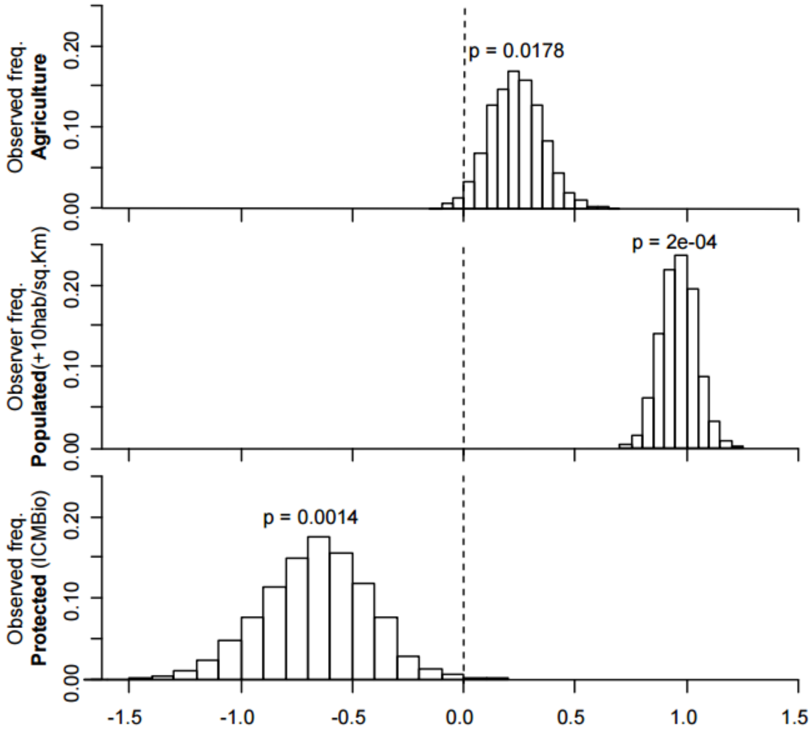


Figure 10. Differences in potential number of uses of the tree assemblages (inside – outside) for each study case: agriculture vs non-agriculture, populated vs non-populated, and legally protected vs unprotected. Computed from 5000 sub-samples of spatially independent observations.

The total impact of agriculture clearings on the tree ecosystem services' value is 13.9% of the total estimated value pre-colonization (based on 2001-2010 agriculture cover), *i.e.,* 13.9% of the hypothetical total value of natural tree vegetation before colonization has been removed for cash crops. The impact caused by cities and any kind of built-up environment (*e.g.,* roads) has been estimated as 0.56%.

Discussion

We found clear evidence that the tree clearings on the Cerrado have not been casual; the trees that provide more provisioning services have been cleared preferentially. This is not, by any mean, to be understood as humans being rude with natural systems for no reason. A priori, the relation found between agriculture and urban establishment and potential ecosystem services provided in an area, does not necessarily mean causality, *i.e.*, not because tree communities had more uses there in the past, human selected those areas to set permanent colonies. Such phenomenon, needing further study to be unveiled, could be possibly due to other underlying factors (such as slope, temperature, etc.) that make a certain area good for service provider species and at the same time attractive for economic development. In follow up studies, we could better establish what is the most important factor to cause this behavior, a possible candidate is water table level. Many tree species in the Cerrado are known to have special capabilities to extract water from deep into the soil. If these species were to be found to be also those that provide a good amount of services, the overlapping of humans and high value communities could be explained; since humans also make use of areas with easy access to groundwater for consumption and agriculture.

The results point in the same direction of previous work carried out to better the conservation of the Cerrado concerning to mammals. We could pointless discuss about the inadequate distribution of human population in the Cerrado: Falerio & Loyola (2013) found that mammal rich sites do also overlap with human population and anthropogenic land use. However our results by no means should be understood to imply wrong positioning of the protected areas. Carvalho et al. (2010) also explored the degree of conservation offered by the current network of protected areas to mammals, finding that protected areas do cover 52% of all high diversity sites in the Cerrado. Our intended use for the developed cartography does not imply that all high value SoU sites should be protected; however, their value should be considered and managed accordingly, rather than converted to cash crop or other land uses. As a matter of fact, preliminary analysis indicate that there is no correlation between biodiversity and number of provided services, meaning that selecting areas with a high number of services does not equals selecting high biodiversity areas.

While we accounted for the services provided by trees, most of the Cerrado vegetation is composed by herbs as denoted by Ratter et al. (1997). In order to measure the total value of the vegetation in the Cerrado, and get a complete picture, adding herbs to the mix is needed. This is though, far from possible today due to the lack of an inventory of herbs (distribution and uses of the species) big enough to enable such analysis.

Fully dedicating areas of Cerrado to tree ecosystem service extraction must be done carefully, fire suppression can have contrary effects in systems that suffer natural occasional fires. As a grassy biome, fire exclusion and tree planting in the Cerrado leads to increase tree density and decrease of plat and faunal diversity: this lead to an increased transpiration of soil water, a decreased belowground to aboveground biomass ratio and increased of fire sensitive tree population (Veldman et al., 2015).

When estimating the impact, we only accounted for agriculture area (cash crops during the period 2001-2010, ~15% of the total area), however we must consider that deforestation in the Cerrado extends father than just the area used for agriculture: 49% of the Cerrado has been deforested. Pasture lands double the extension of agriculture. There might be, though, very sparce trees in pasture lands too; in fact, these scattered trees are known to be keystone structures for the savanna ecosystem (Manning et al., 2006). While the trees might not be cleared in a consistent manner, cattle are possibly preventing them from growing. In addition, these areas suffer from episodic fires, that, while natural in the dynamics of the Cerrado, if intentional and too frequent, can cause the deterioration of the whole system and limit the reproduction of adjacent tree covered landscapes.

Although this study has been carried out using the best available methods as of today, we cannot forget that the hypotheses have been tested on "*models based on models that were based on models*". Though nowadays this issue is common in many ecological studies, rarely one can see all the modelling steps in the same manuscript; we developed a high-level index (namely the sum of all provisioning ecosystem uses, SoU) solely based on three raw inputs: a matrix of weather stations; a matrix of units where tree species were sampled; and a matrix containing the species' uses.

Multi-species distribution modelling is an emerging field that allow us model higher level features such as potential species assemblage distributions. Our modelled "potential communities" incur on an extremely important assumption: there is no competition or exclusion between the modelled species, therefore we have been referring to it as "species assemblages" rather than communities. This is of little relevance in the study, since there was no interested on unveiling the community composition, but on the mean traits of the resulting species assemblages. Modelling potential distributions, in order to solve applied ecological problems and better understand the system dynamics is still to be better explored, we believe that the present study can also settle the basis for such projects.

The developed cartography can further help the underlined objectives recently published by Strasburg et al., (2017). To be precise, the modelled distribution of potential uses will further help improving incentives for Cerrado restoration as well as the incentives to retain Cerrado. Each of these policies are already in place in some form. Strasburg et al., also postulate that restoration is key for the conservation of the Cerrado. We completely agree with this claim. Restoration together with sustainable use of the tree resources would not only enhance the biome conservation status, but provide certain amount of income if carried out properly.

We believe that Real SoU can very roughly approximate to economic value. Establishing the relation between SoU and price per area (\$ m^{-2}) can contribute new insight in order to explore and extract in a sustainable way new sites: although, SoU, *per se,* serves this purpose, we do not have an estimative of the return of investments of using the natural vegetation in any given XY location. A future study can estimate the relation of SoU -or another newly developed index based on our present modeling- with monetary value of the ecosystem services. We believe such study can be done by surveying Cerrado cooperatives and tracing down the amount of earnings that can be made by sustainable extraction. By means of linear regression (or other machine learning approaches) the economic value per area (\$ m^{-2}) can be linked to Real SoU, which could help establishing the value in actual currency of the provisioning services of the Cerrado. After linking monetary value to our index, we could also consider how much area of the Cerrado has resource in such low density that extraction would not be lucrative. In the current study, we assume that there is value for human regardless of density or how sparse the trees are, which might not reflect a real-world situation.

In the current reasoning of ecosystem service price tagging, if we could make a higher economic income from the natural vegetation there would be a lower incentive to deforest the Cerrado. By being able to conserve natural vegetation due to its human derived value (opposed to its intrinsic value, e.g., biodiversity), we can make sure that fauna and flora will not be so endangered even if there are not protected areas on place. As highlighted by Strassburg et al (2017), this is the moment of truth for the Cerrado. Prioritization is not focused as of now in conserving the most affordable areas, but, maybe, those closer to pristine state. We found evidence that Cerrado conservation, as of now, does not account for the value that human could derive from natural trees. This is a key factor that we must consider if we want to extend a certain degree of protection to the full extent of the Cerrado.

Chapter 5

Conclusions

- The developed cartography can potentially be useful in future conservation prioritization and decision making in the Cerrado.
- We evidence that cash crops and built-up environment cleared preferentially the areas that could be inhabited by better than average provisioning service providers.
- We evidence that protected areas are located where natural vegetation is expected to have lower than average provisioning services.
- We estimate that 13.9% of the total resources that could be extracted from the natural tree species has been lost due to agriculture clearings alone.

Conclusões

- A cartografia desenvolvida tem grande uso potencial na futura priorização de conservação e tomada de decisões no Cerrado.
- Evidenciamos que a agricultura e as cidades eliminaram preferencialmente as áreas que poderiam potencialmente ser habitadas por fornecedores de serviços de aprovisionamento melhores do que a média.
- Comprovamos que as áreas protegidas estão localizadas em áreas onde a vegetação natural deve ter menor quantidade de serviços de abastecimento.
- Estimamos que 13,9% dos recursos totais que poderiam ser extraídos das espécies arbóreas naturais foram perdidos apenas por clareiras agrícolas.

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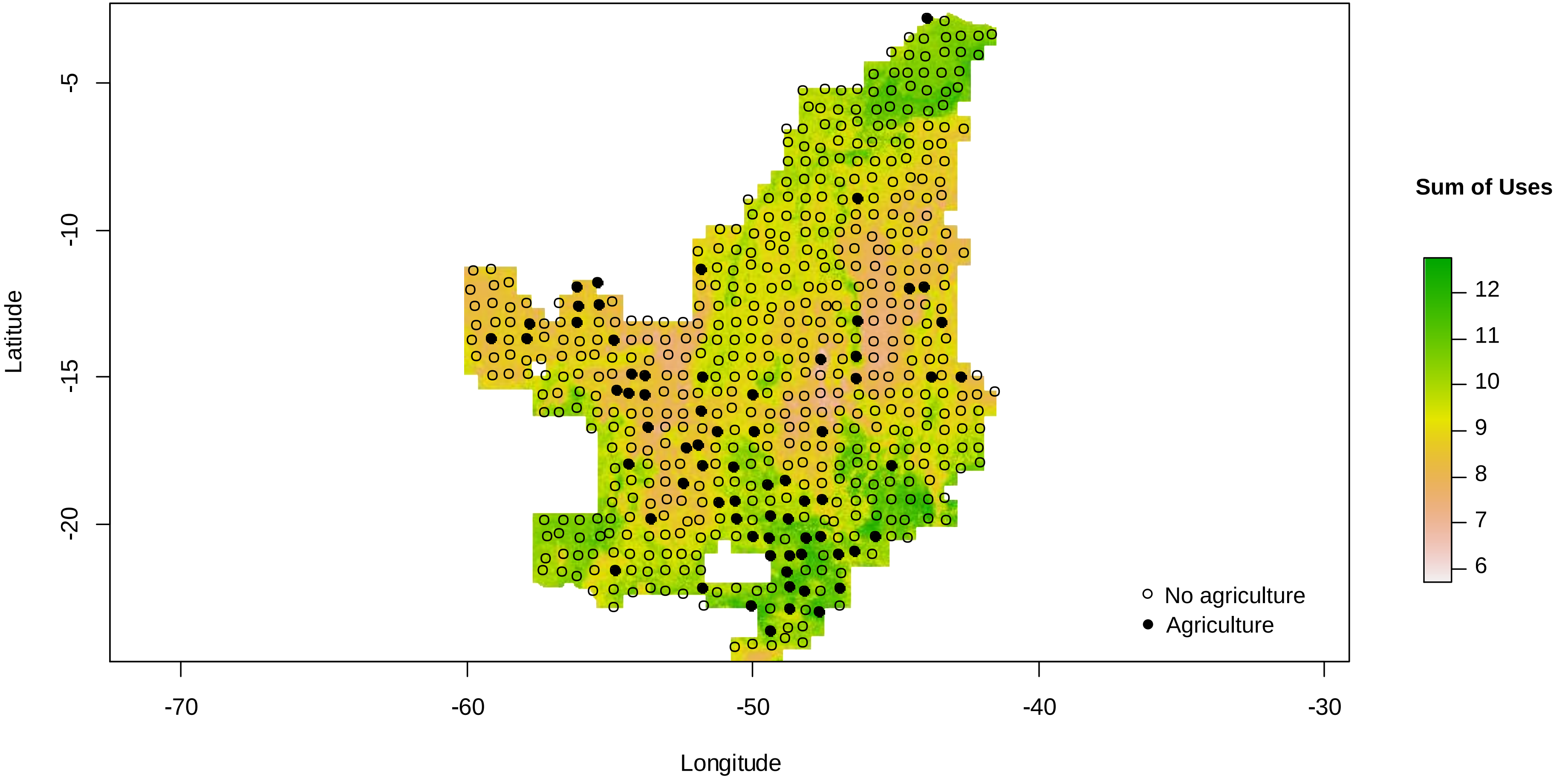
Appendix A



Appendix A. Sample Floating Gaussian Grid used to sample spatially independent data points from the Cerrado's *sum of uses* index.

Appendix B

Average Annual Temperature				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept	29.4156	0.234409	125.49	<2e-16
Altitude	-0.00511	0.000367	-13.93	<2e-16
Latitude	0.209426	0.018927	11.06	<2e-16

```
R-squared: 0.8664   Adjusted R-squared : 0.8645
Residual std. error: 1.035 on 143 deg. Freedom
```

Maximum Annual Temperature				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	31.77847	1.359275	23.379	< 2e-16
Altitude	-0.0049	0.000521	-9.421	< 2e-16
Latitude	0.201097	0.027836	7.224	2.82E-11
Longitude	-0.08787	0.030322	-2.898	0.00435

```
R-squared: 0.782,     Adjusted R-squared: 0.7774
Residual std. error: 1.341 on 142 deg. of freedom
```

Minimum Annual Temperature				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept	24.31834	0.233256	104.26	<2e-16
Altitude	-0.00505	0.000365	-13.83	<2e-16
Latitude	0.215776	0.018834	11.46	<2e-16

```
R-squared:  0.8689, Adjusted R-squared:   0.8671
Residual std. error: 1.03 on 143 deg. of freedom
```

Relative Humidity				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	197.1782	7.332753	26.89	<2e-16
Latitude	1.127209	0.082373	13.684	<2e-16
Altitude	-0.02552	0.001638	-15.575	<2e-16
Longitude	-0.65474	0.067658	-9.677	<2e-16
Avg.Temp	-5.33317	0.241777	-22.058	<2e-16

```
R-squared:  0.7978,    Adjusted R-squared:  0.7921
Residual std. error: 2.961 on 141 deg. of freedom
```

Total Precipitation				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept	-3.41E+03	6.97E+02	-4.888	2.78E-06
Altitude	-5.35E+00	9.26E-01	-5.773	4.87E-08
Latitude	-2.59E+02	4.94E+01	-5.236	5.94E-07
Longitude	-1.14E+02	1.55E+01	-7.333	1.69E-11
Lat:Lon	-6.40E+00	1.05E+00	-6.065	1.18E-08
Alt:Lon	-8.35E-02	2.06E-02	-4.048	8.52E-05
Alt:Lat	-9.03E-02	1.20E-02	-7.548	5.29E-12

```
R-squared:  0.609,     Adjusted R-squared:  0.5921
Residual std. error: 223.5 on 139 ded. of freedom
```

Real Evapotranspiration				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-8.9317	7.108665	-1.256	0.211
Longitude	-1.22612	0.172328	-7.115	6.10E-11
Altitude	-0.01249	0.001957	-6.383	2.63E-09
Precipit	0.025808	0.002032	12.699	<2.00E-16

```
R-squared:  0.7905,    Adjusted R-squared:  0.7858
Residual std. error: 7.037 on 134 deg. of freedom
```

Potential Evapotranspiration				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept	-83.5839	8.899	-9.392	<2e-16
Avg.Temp	8.5903	0.3745	22.936	<2e-16

```
R-squared:  0.7946,    Adjusted R-squared:  0.7931
Residual std. error: 12.29 on 136 deg. of freedom
```

Piche Evapotranspiration				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	370.1086	31.1735	11.873	<2e-16
Rel. Humid.	-4.5884	0.2964	-15.48	<2e-16
Avg.Temp	3.8118	0.6847	5.567	1.24E-07

```
R-squared:  0.7335,    Adjusted R-squared:  0.7298
Residual std. error: 21.43 on 143 deg. of freedom
```

Number of cloudy days (year)				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept	103.6082	15.08099	6.87	1.82E-10
Diurnal Va	-5.44513	1.103771	-4.933	2.22E-06
Precipit	0.064336	0.004375	14.704	< 2e-16

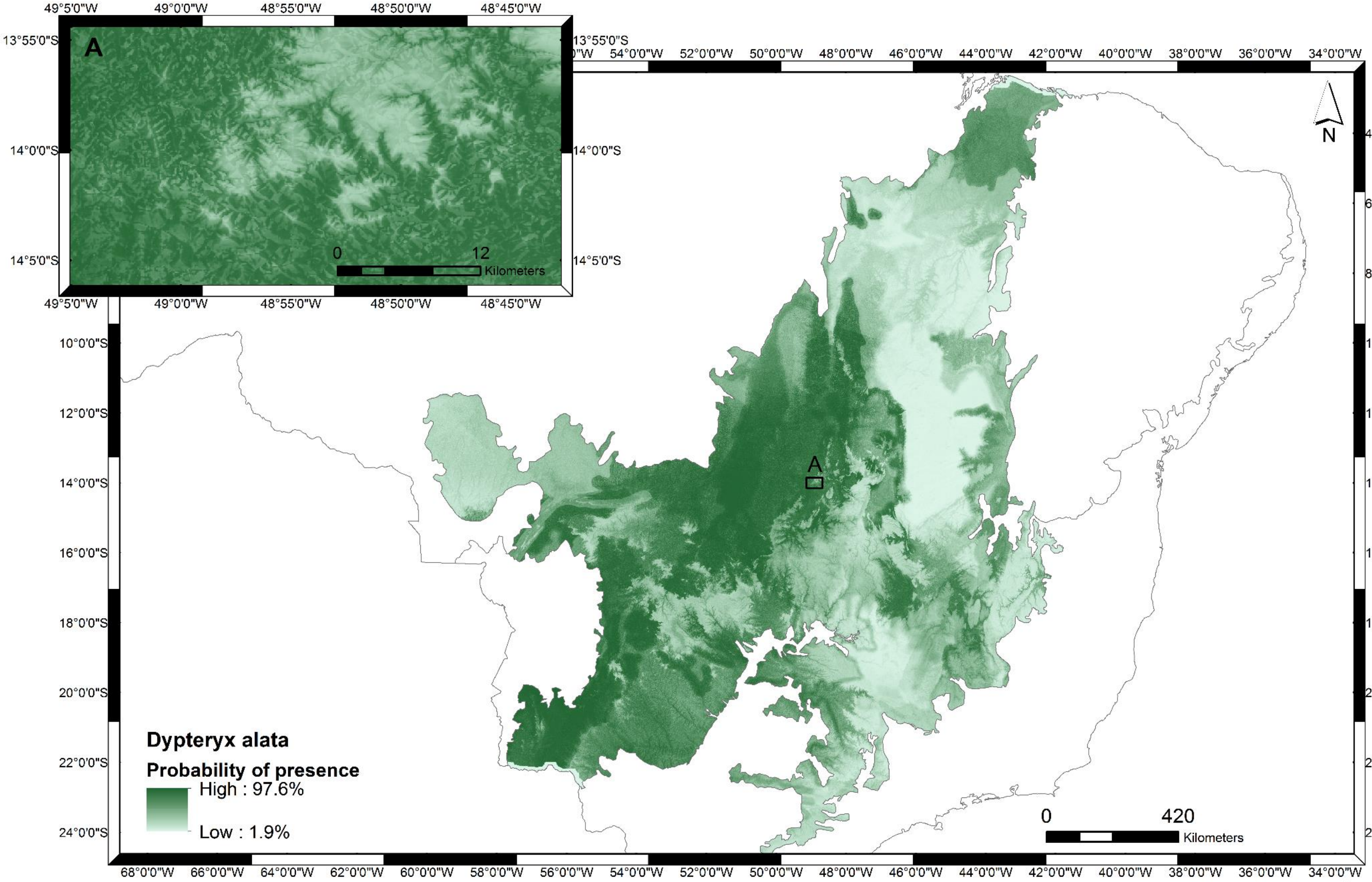
```
R-squared:  0.6499,    Adjusted R-squared:  0.645
Residual std. error: 18.26 on 143 deg. of freedom
```

Average Wind Speed				
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	15.77564	1.821238	8.662	1.43E-14
Latitude	0.729959	0.112933	6.464	1.81E-09
Longitude	0.268587	0.03896	6.894	2.02E-10
Pot. Evap.	-0.00968	0.003094	-3.128	0.00216
Lat:Lon	0.014926	0.002417	6.177	7.55E-09

```
R-squared:  0.3506,    Adjusted R-squared:  0.3309
Residual std. error: 0.5712 on 132 deg. of freedom
```

Appendix B. Parameters and goodness of fit metrics of the linear models used for climatic modelling.

Appendix C



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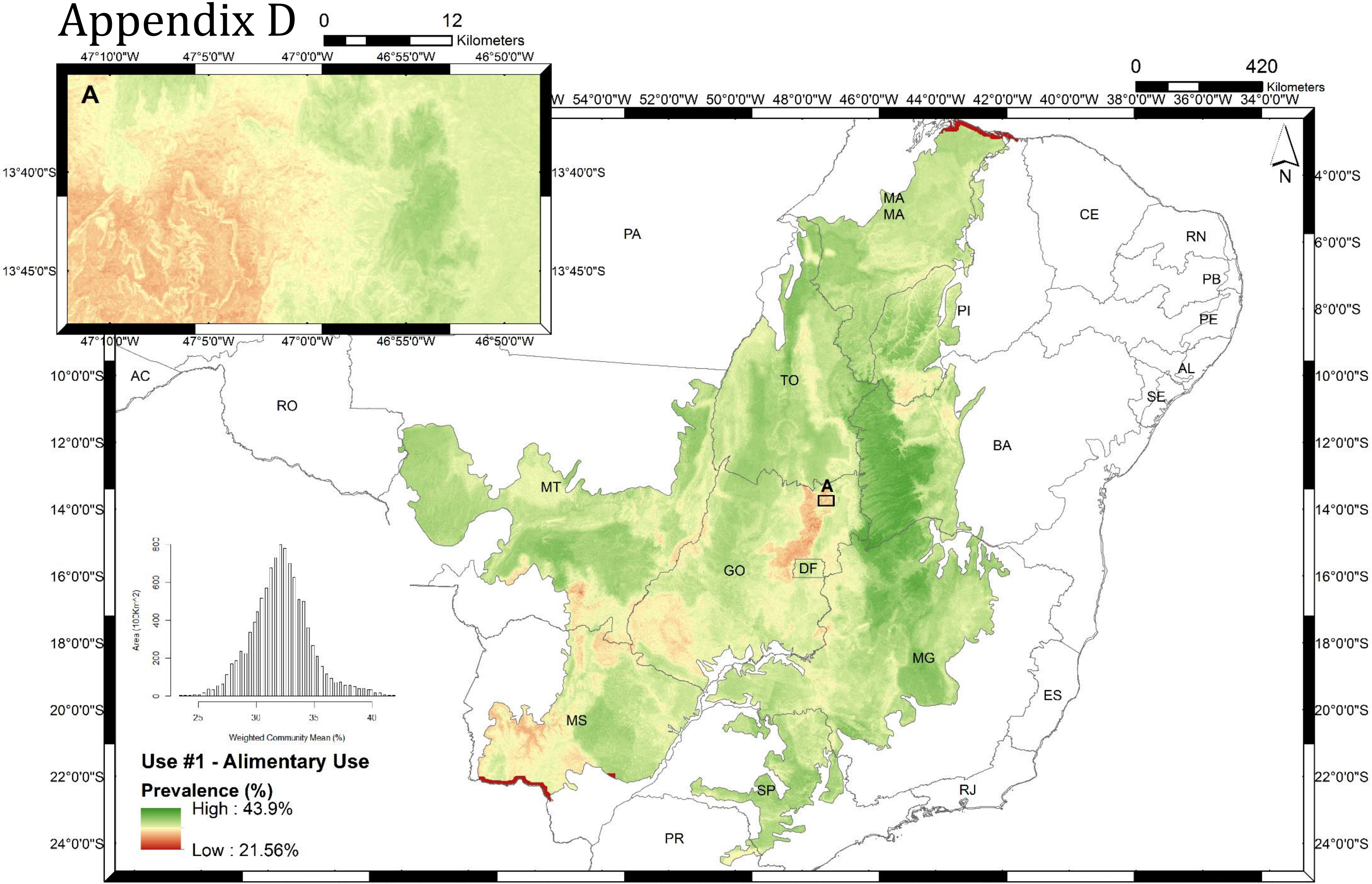
Authors: Requena, C.; Rocha, F.S.; Duarte, L. D. S. ;

Appendix C. Sample of species distribution model (*Dypteryx alata*). All 93 species distribution can be accessed contacting the first author.

Appendix D



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Coordinate System: GCS WGS 1984
Datum: WGS 1984
Units: Degree

Authors: Requena, C.; Rocha, F.S.; Duarte, L. D. S. ;

Appendix D. Sample distribution of provisioning service (Alimentary). All 20 provisioning services can be accessed contacting the first author.

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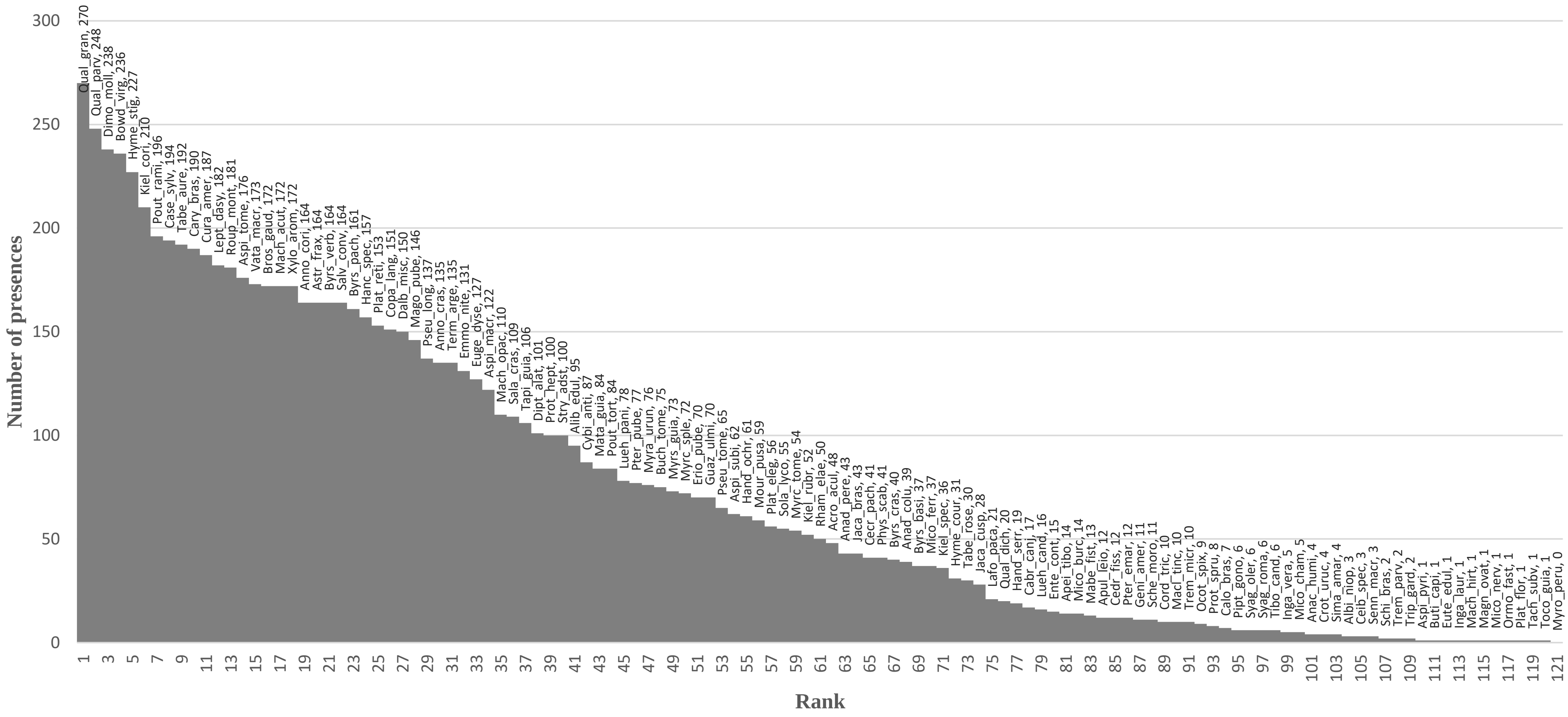
Appendix E

1. Acrocomia aculeata
2. Alibertia edulis
3. Anadenanthera colubrina
4. Anadenanthera peregrina
5. Annona coriacea
6. Annona crassiflora
7. Apeiba tibourbou
8. Apuleia leiocarpa
9. Aspidosperma macrocarpon
10. Aspidosperma subincanum
11. Aspidosperma tomentosum
12. Bowdichia virgilioides
13. Buchenavia tomentosa
14. Byrsonima basiloba
15. Byrsonima crassifolia
16. Byrsonima pachyphylla
17. Byrsonima verbascifolia
18. Cabralea canjerana
19. Calophyllum brasiliense
20. Caryocar brasiliense
21. Casearia sylvestris
22. Cecropia pachystachya
23. Cedrela fissilis
24. Copaifera langsdorffii
25. Cordia trichotoma
26. Curatella americana
27. Cybistax antisyphilitica
28. Dalbergia miscolobium
29. Dimorphandra mollis
30. Dipteryx alata
31. Emmotum nitens
32. Enterolobium contortisiliquum
33. Eriotheca pubescens
34. Eugenia dysenterica
35. Genipa americana
36. Hancornia speciosa
37. Handroanthus ochraceus
38. Handroanthus serratifolius
39. Hymenaea courbaril
40. Hymenaea stigonocarpa
41. Inga vera
42. Jacaranda brasiliana
43. Jacaranda cuspidifolia
44. Kielmeyera rubriflora
45. Kielmeyera speciosa
46. Lafoensia pacari
47. Leptolobium dasycarpum
48. Luehea candicans
49. Luehea paniculata
50. Mabea fistulifera
51. Machaerium acutifolium
52. Machaerium opacum
53. Maclura tinctoria
54. Magonia pubescens
55. Matayba guianensis
56. Miconia burchellii
57. Miconia chamissois
58. Miconia ferruginata
59. Mouriri pusa
60. Myracrodruon urundeuva
61. Myrcia splendens
62. Myrcia tomentosa
63. Ocotea spixiana
64. Physocalymma scaberrimum
65. Piptadenia gonoacantha
66. Plathymenia reticulata
67. Platypodium elegans
68. Pouteria ramiflora
69. Pouteria torta
70. Protium heptaphyllum
71. Protium spruceanum
72. Pseudobombax longiflorum
73. Pseudobombax tomentosum
74. Pterodon pubescens
75. Qualea dichotoma
76. Qualea grandiflora
77. Qualea parviflora
78. Rhamnidium elaeocarpum
79. Roupala montana
80. Salacia crassifolia
81. Salvertia convallariodora
82. Schefflera morototoni
83. Solanum lycocarpum
84. Stryphnodendron adstringens
85. Syagrus oleracea
86. Syagrus romanzoffiana
87. Tabebuia roseoalba
88. Tapirira guianensis
89. Terminalia argentea
90. Tibouchina candolleana
91. Trema micrantha
92. Vatairea macrocarpa
93. Xylopia aromatic

Appendix E. List of modelled tree species.

Appendix F



Appendix F. Species ranking by number of detected presences in the 312 plots sampled in the Cerrado. Only the 93 most common species where used in the study.