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Spatial arrangements of green areas in a megacity and their effects on human health

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Dissertação apresentada ao Instituto de Biociências da Universidade de São Paulo, para a obtenção de Título de Mestre em Ciências, na Área de Ecologia.

Orientador: Dr. Jean Paul Metzger
Coorientadora: Drª Simone R. de Freitas

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Dedicatória

A cada árvore derrubada e a cada árvore que resiste na maior metrópole do hemisfério Sul.

Epígrafe

Um dos primeiros atos dos marinheiros portugueses que, a 22 de abril de 1500, alcançaram a costa sobrecarregada de floresta do continente sul-americano, nos 17 graus de latitude sul, foi derrubar uma árvore. Do tronco desse sacrifício ao machado de aço, confeccionaram uma cruz rústica – para eles o símbolo da salvação da humanidade. Uma missa então foi celebrada aos pés dessa cruz, durante a qual, para satisfação dos portugueses, os indígenas ali aglomerados imitaram sua postura ajoelhada, com as mãos em prece, embora não imitassem suas expressões devotas [...].

Os indígenas, que inconscientemente se irmanaram com eles naquela praia, não faziam ideia, tal como as árvores às suas costas, da destruição que essa invasão causaria.

Warren Dean, *A ferro e fogo*
(trad. Cid Knipel Moreira)

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Introdução Geral

A maior parte da população no mundo vive em cidades (55%, ou seja cerca de 4,125 bilhões de pessoas) e estima-se que até 2050 sejam 6,5 bilhões de pessoas vivendo em ambientes urbanos (65%) (ONU, 2017; ONU, 2018). A vida nas cidades impulsiona uma tendência de adensamento populacional onde cada espaço da cidade é pensado para habitação e serviços inerentes ao modo de vida urbano, restando poucas áreas disponíveis para a presença de infraestruturas verdes.

O modo de vida urbano tem propiciado cada vez menos o contato com a natureza, resultando praticamente na extinção da experiência direta com os elementos naturais (Miller, 2005; Soga & Gaston, 2016). Durante toda a história evolutiva da espécie tivemos uma íntima relação com os ambientes naturais e a biodiversidade (Verbeek & Waal, 2002), o que tem se tornado escasso, propiciando o surgimento de doenças e a diminuição do bem-estar (Bertram & Rehdanz, 2015; Gaston & Soga, 2020). A necessidade de contato com a biodiversidade é chamada de "biofilia" (Kellert & Wilson, 1993; Wilson, 1984), e ela seria um dos fatores pelos quais os ambientes urbanos tendem a causar estresse e impactar a saúde dos moradores das cidades, na ausência da dose de verde necessária para o bem-estar (Shanahan et al., 2015).

Parte da solução do problema baseia-se no entendimento dos efeitos dos diferentes arranjos espaciais do verde urbano sobre a saúde das pessoas (Soga et al., 2015). Sob essa perspectiva podemos encontrar nas soluções baseadas na natureza (Cohen-Shacham et al., 2019; van den Bosch & Ode Sang, 2017) um caminho para a melhoria do bem-estar nas cidades, através dos chamados "serviços ecossistêmicos" (Bush & Doyon, 2019), que são benefícios que as pessoas obtêm dos ecossistemas e afetam sua qualidade de vida (MEA, 2005). Nas cidades, esses serviços podem se dar tanto na forma de regulação, como efeitos na diminuição do calor, ruídos e poluição do ar (Fang & Ling, 2005; Nowak et al., 2006; Oliveira et al., 2011; Solecki et al., 2005), mas também em termos culturais, como a apreciação da beleza cênica, práticas de atividades físicas e sensação de tranquilidade (Araya et al., 2007; Astell-Burt et al., 2014; Ngom et al., 2016; van den Berg et al., 2010). Esses serviços podem afetar positivamente uma série de aspectos da saúde humana, como a saúde respiratória, por

meio do controle da qualidade do ar (Theophilo et al., 2021), e também a saúde mental e a diminuição do estresse, o que pode estar ligado à saúde cardiovascular (Roe et al., 2013).

A quantidade de verde e a forma como ele está distribuído no espaço urbano pode afetar a provisão desses serviços nas cidades, e, portanto, a saúde de seus moradores. Duas formas de distribuição do verde nas cidades podem ser distinguidas: o *land sharing (compartilhamento de terras)* e o *land sparing (segregação de terras)* (Lin & Fuller, 2013; Soga et al., 2014; 2015). No primeiro caso, o verde estaria mais difuso no espaço, compartilhando espaço com áreas construídas, enquanto no segundo caso as áreas verdes e cinzas são bem estabelecidas, não havendo mistura, com a intensificação de uso humano em algumas áreas e, separadamente, espaço verdes de maior qualidade em outras. *Land sharing* e *land sparing* são duas abordagens distintas de conservação, aplicadas originalmente a ambientes rurais (Fischer et al., 2014; Grau et al., 2013), sob uma lógica de produtividade e conservação da biodiversidade. No *land sparing* haveria um uso mais intensivo do solo em algumas áreas, enquanto outras áreas são reservadas para vegetação de maior qualidade. Já no *land sharing* o uso do solo é menos intenso, porém mais extensivo, conciliando a vegetação nativa com a produtividade em um mesmo espaço. Para as cidades, o uso dessa abordagem ainda é pouco explorado, mas igualmente relevante para o entendimento das dinâmicas da paisagem no ambiente urbano, visto que podem existir complexas redes de oferta e de demanda de serviços ecossistêmicos (Field & Parrott, 2017; Metzger et al., 2020), que podem depender de diferentes estratégias de conservação das áreas verdes para funcionarem (Dennis & James, 2016).

Os padrões de ocupação *land sharing* e *land sparing* nas cidades se dão por diferentes elementos do verde presentes nas áreas urbanas. Enquanto pequenas áreas verdes, praças, jardins e a própria arborização de calçadas cumpre um papel mais relacionado ao *land sharing*, parques urbanos de maior porte, remanescentes de vegetação nativa, áreas de preservação permanente em beiras de corpos d'água e unidades de conservação inseridas dentro do tecido urbano, ou em áreas periurbanas, cumprem um papel associado ao *land sparing*. Em megacidades ao redor do mundo há uma alta densidade populacional, equivalente a intensa ocupação do solo na abordagem de *land sparing*. Em países de primeiro mundo é comum encontrar os

chamados subúrbios, onde extensas áreas são ocupadas por moradias de baixa densidade populacional, formando vizinhanças com abundante vegetação entre as casas, com jardins e calçadas bem arborizadas, enquanto nas regiões mais centrais das cidades há uma maior densidade de construções e pessoas, com algumas áreas reservadas ao lazer e prática de esportes como os parques urbanos (Soga et al., 2014). Já em países como menor nível de planejamento urbano e maior desigualdade social, como no caso da América Latina (Dobbs et al., 2018), esse padrão entre a região central, os subúrbios e as áreas periurbanas não pode ser observado com tanta facilidade. Por outro lado, há um padrão claro de associação da cobertura verde com as regiões mais ricas de algumas cidades (Arantes et al., 2021).

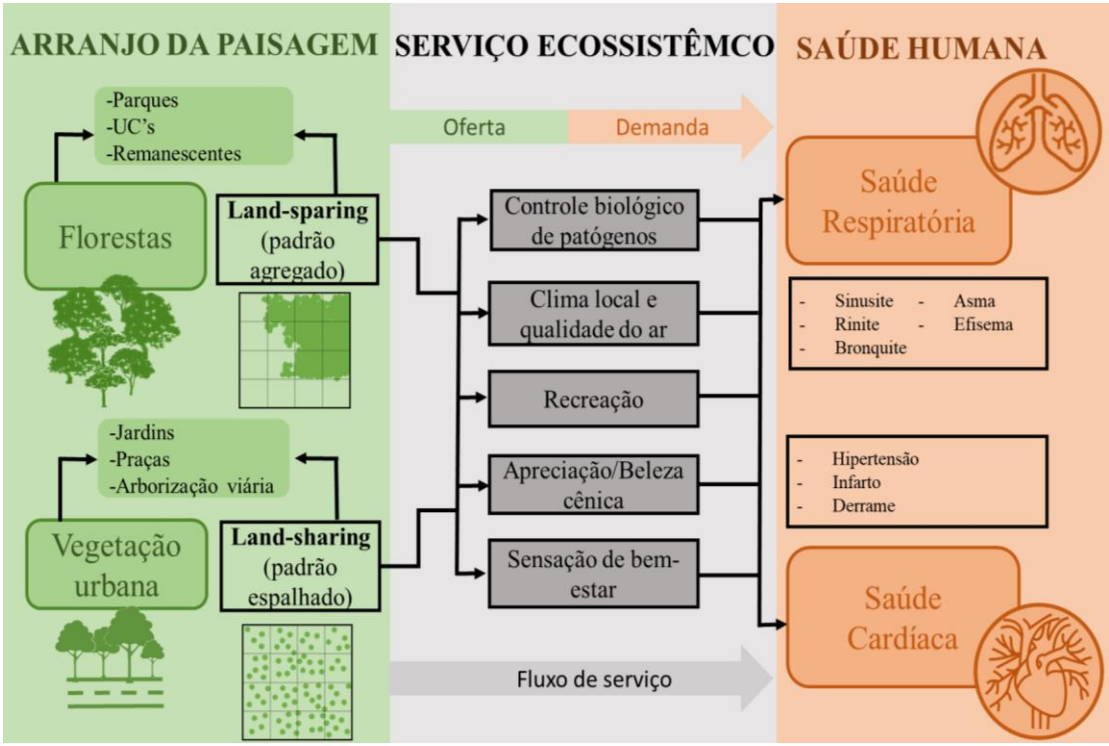

Figura 1 – Abordagem teórica da oferta dos serviços ecossistêmicos por diferentes arranjos do verde e seus potenciais impactos na saúde cardíaca e respiratória, apresentando algumas doenças que podem estar relacionadas com a oferta de alguns serviços ecossistêmicos nas cidades.

O fluxo de serviços ecossistêmicos na cidade pode ter como áreas de oferta tanto a vegetação distribuída em um padrão *land sharing* quanto *land sparing* (Figura 1), e pouco se sabe sobre o efeito desses dois tipos de distribuição sobre a saúde dos moradores. Aqui investigaremos como algumas doenças comuns do sistema respiratório e cardiovascular estão ligadas à cobertura e à distribuição do verde na maior megacidade do hemisfério sul, São Paulo, Brasil. Vamos testar como diferentes padrões de distribuição contribuem de forma diferente para a diminuição da

ocorrência de doenças na população usuária do sistema público de saúde. Apresentaremos uma forma inovadora de mensurar os níveis de *land sharing* e *land sparing* em diferentes regiões da cidade, baseados em estudos anteriores que se debruçaram sobre o tema (Soga et al., 2014; Stott et al., 2015), buscando a associação dessas métricas com a saúde dos moradores de São Paulo.

CAPÍTULO 1:

CONTRASTING EFFECTS OF URBAN LAND SHARING AND LAND SPARING ON RESPIRATORY AND CARDIOVASCULAR DISEASES

CONTRASTING EFFECTS OF URBAN LAND SHARING AND LAND SPARING ON RESPIRATORY AND CARDIOVASCULAR DISEASES

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ABSTRACT

The benefits of green infrastructure in preventing disease in urban areas are already well established, with strong evidence that the amount and proximity to green areas have a positive effect on well-being. However, the understanding of how the spatial distribution and type of green areas affect health is still incipient. Here, we explore how different configurations of green and built-up areas, through a land sharing and sparing framework, and how green areas with different green density affect hospitalizations per cardiovascular and respiratory causes in São Paulo city, Brazil. To access the degree of land sharing and land sparing, we propose new continuous indicators based in vegetation indexes images. Hospitalizations per cardiovascular and respiratory causes were obtained from a public health dataset. We construct binomial linear models considering hospitalization rates, vegetation characteristics and indicators of land sharing and land sparing. We found that sharing/sparing spatial arrangements were selected as a main explanatory factor in the control of all groups of diseases. Land sharing appeared as a favorable spatial condition to prevent cardiovascular hospitalization, while land sparing and arboreal vegetation were relevant to reduce hospitalization by inferior respiratory diseases. However, for superior respiratory diseases we found a possible disservice of dense forests, which were associated with increasing rates of hospitalization. Considering that the hospitalization rates and the severity of cardiovascular diseases tend to be higher than those of superior respiratory ones, dense vegetation tend to provide more services than disservices. The land sharing configuration should lead to greater exposure and usufruct of the benefits of green areas, which may explain the greater prevention of cardiovascular diseases. These results indicate that a more balanced distribution of green areas across built-up areas creates healthier urban spaces. Decision makers should consider increasing land sharing in urban landscape planning, as a way to leverage the benefits of green infrastructure.

Key-words: Ecosystem Services; green infrastructure; landscape structure; human health; urban landscape

INTRODUCTION

The association between green infrastructure and human health in cities has been extensively studied, in most cases showing a positive association between the amount and proximity to green spaces with a reduction of the risk of cardiovascular (Moreira et al., 2020) and respiratory diseases (Ferrante et al., 2020; Lotufo, 2017). However, the understanding of the effects of green areas qualities and their spatial arrangement in relation to built-up areas on the provision of health benefits is still an open question. In particular, it is not clear if it is more interesting to have large green areas (e.g. well preserved urban parks), or is it better to have the green areas scattered and diffuse in the urban landscape, favoring proximity in relation to the extension and quality.

The benefits of green areas to human health are mediated by ecosystem services, particularly by regulating services, as air quality and temperature control (Almeida et al., 2018), and cultural services, as recreation and aesthetic appreciation (Hegetschweiler et al., 2017; Jennings & Gaither, 2015; Shi et al., 2020). Urban forests and other green areas can provide both services, reducing air pollutants and promoting recreation activities, impacting physiological, respiratory, and mental health (James et al., 2015; Kondo et al., 2018; Nieuwenhuijsen et al., 2017). Urban vegetation can play an important role in respiratory diseases occurrence, mostly through the regulation of air pollution (Alcock et al., 2017; Lotufo, 2017; Squillacioti et al., 2020; Tischer et al., 2017). Cultural services such as recreational activities, sport practicing, scenic view appreciation (Kosanic & Petzold, 2020; Tengberg et al., 2012) can control the production of hormones like cortisol (Roe et al., 2013) and even reduce the risk of cardiac diseases (Astell-Burt & Feng, 2020; Moreira et al., 2020; Plans et al., 2019; Yeager et al., 2020). By encouraging outdoor activities and sport practice, green areas near people can reduce cardiovascular risk factors, as overweight, hypertension, cholesterol levels and diabetes (Yeager et al., 2020).

Several factors can mediate the relationships between the potential provision of a service and its contribution to human health, as the amount of green (Plans et al., 2019), the use of the green areas (Kaczynski et al., 2014; Tamosiunas et al., 2014) or the exposure to nature (Shanahan et al., 2015, 2016), the proximity between green and inhabited areas (Kaczynski et al., 2014; Moreira et al., 2020), and the quality or type of vegetation. Green area quality may be related to biodiversity, biomass, or structural

complexity parameters, which are known to affect human well-being and health (Methorst et al., 2021). For example, green areas and gardens play different roles in asthma than tree density, according to a cross-sectional study in England (Alcock et al., 2017), showing the importance of consider the type of green. The understanding of the spatial arrangement of green areas on health are generally limited to a proximity effect, but these analyses disregard the general pattern of the landscape, given its degree of fragmentation or the degree of intersection between green and built areas (Mitchell et al., 2015).

A broader framework for assessing spatial distribution of green areas is provided by the land sharing and land sparing strategies (Lin & Fuller, 2013; Soga et al., 2014; Stott et al., 2015). Land sparing is a conservation strategy that combines the intensification of human use in some areas (in principle, the areas with the most favorable conditions for this activity), with setting aside other areas for conservation of more preserved (with higher quality) native vegetation (Balmford et al., 2012). On the other side, land sharing strategy promotes less intensive use in more extensive areas, leading to a shared use of the same space for production and conservation purposes. In urban areas, a land sparing configuration can typically be represented by neighborhoods with a high population density and with the presence of well-maintained green areas (parks, squares). Land sharing is typically represented by neighborhoods of lower population densities, with plenty of green areas among households, as occurs in many suburbs of cities in more developed countries. The effect of urban sharing and sparing on duration, frequency and intensity of exposure to nature (Shanahan et al., 2015, 2016), and thus on the provision of ecosystem services and human health is still an open question.

Our aim here was to evaluate the relative effects of the quantity, type and spatial distribution of green areas in an urban landscape on the frequency of hospitalizations by cardiovascular and respiratory diseases. We tested those relationships using public data of hospitalization rates in one of the world's largest megacities, São Paulo (Brazil), relating them to the level of land sharing and land sparing, the amount and type of green areas at a neighborhood scale. To perform this analysis, we developed new indicators which allow to assess in a continuous way how the landscape structure reflects the level of land sharing and sparing in a particular region (here, a neighborhood). We expect that (1) greener neighborhood will present lower occurrence of diseases (due to higher

provision of regulating and cultural services); (2) more complex/diverse vegetation types will provide more health benefits; and (3) land sharing schemes will provide more benefits than land sparing schemes if we suppose they allow higher and more frequent exposure of people to green areas.

METHODOLOGY

Study Area

The study was carried in São Paulo city, southeastern Brazil. São Paulo megacity is the biggest metropolis of the south portion of the globe, with an estimated population of 12,325,232 inhabitants in 2020 (IBGE, 2021) and a total area of 1,521.110 km². Its metropolitan region encompasses more than 21,500,000 inhabitants.

São Paulo is located in the Atlantic Rain Forest region, a biodiversity hotspot that was overexploited during the last five centuries, and nowadays no more than 28% of its natural cover remains (Rezende et al., 2018). São Paulo has a significant natural forest cover within its administrative limits, in special two state nature reserves: one in northern region, the State Park of Cantareira (7.62 Kha), and another in south, the State Park of Serra do Mar (322.29 Kha) two continuous forests that extends beyond the city limits. São Paulo city has about 33% of native vegetation cover inside its limits (SVMA, 2020).

For this study, we use as unit of analysis the 96 administrative districts (Figure 1) for which we obtained social and populational data from official sources. These districts present a wide gradient of socioenvironmental conditions in terms of green cover and infrastructure, population, socioeconomic condition and frequency of use of the public health system, known in Brazil as the Universal Health System (in Portuguese, *Sistema Único de Saúde* – SUS; Figure 1).

Health Data

We used the public health dataset of SUS' hospitalizations in the São Paulo city for adults with 20 years or more. The SUS is considered one of the most complete universal health systems in the world, and it is available for all the Brazilian population, free of charge. Beyond SUS, there are many private health systems, used mostly by high-middle

classes and workers with private health insurance systems. About 55% of São Paulo's city population are SUS exclusive users according to an estimation made in 2010 (CEInfo, 2010). This rate changes according to the socioeconomic characteristics and size of the city district, with some of them having no more than 30% of SUS users, while others have more than 70%.

All data was available at the dataSUS database (SUS, 2021), and were processed and georeferenced by the Center of Metropolitan Studies of University of São Paulo (CEM, 2017). For each hospitalization, the cause of hospital admission (according to the International Classification of Diseases code) and the residence address of the patient were recorded. The georeferenced data collection prepared by the Center of Metropolitan Studies was plotted in São Paulo's districts map, allowing the identification of the numbers of hospitalizations by administrative region. We selected three years of data, 2014, 2015 and 2016, that are the last three years available to download in the CEM's platform (CEM, 2021; https://centrodametropole.fflch.usp.br/pt-br/download-de-dados), and considered three group of diseases (cardiovascular, superior and lower respiratory system diseases), which are known to be regulated by the availability and use of green areas (Table S1 – supplementary material).

Once our analyses were restricted to the population that uses SUS, we considered just the estimated fraction of SUS users for each district, as presented by the municipal health secretariat (CEInfo, 2010). According to the last census, from 2010, the population for the whole city was 11,253,203 inhabitants (IBGE, 2010), of which circa of 6,100,000 are SUS users (IBGE, 2010; CEInfo, 2010). The proportion of users for each district was estimated using the Brazilian Census (IBGE, 2010) of each district, and the percentage of SUS users per district (CEInfo, 2010).

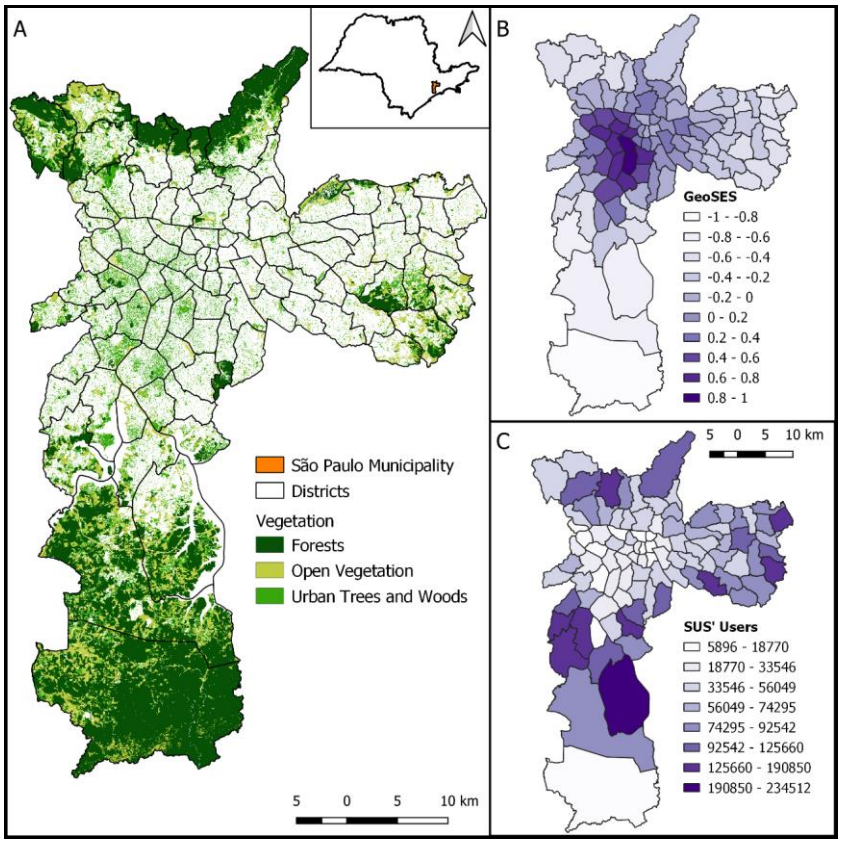

Figure 1. (A) Native vegetation cover in São Paulo City districts; (B) Social conditions represented by GeoSES Index (Barrozo *et al.* 2019; highest values represent better conditions); and (C) Estimated number of Universal Health System (SUS) users.

Socioeconomic Data

To control socioeconomic conditions, we used the GeoSES indicator (Barrozo et al., 2019). This metric was developed as an alternative for the Human Development Index (HDI), incorporating seven socioeconomic dimensions: education, mobility, poverty, wealth, income, segregation, and deprivation of resources and services. GeoSES have a great explanatory power for relative risks of some diseases, and, different from HDI, it does not have a longevity component, avoiding mathematical redundancy for health researches (Barrozo et al., 2019). We used GeoSES values obtained for each of the 96 districts with the 2010 Brazilian Census data, as a co-variable for all statistic models.

Landscape and Vegetation Data

For landscape composition analysis, we used the vegetation cover map of São Paulo municipality (SVMA, 2020). The data consists of a vegetation cover vectorization and classification in the resolution of 1:1000 inside the city and 1:5000 within protected areas, based on orthophotos with 0.12 m of resolution, from 2017, obtained by municipal

environment office. The original data has 15 categories, but for this study we reclassified it into three types of vegetation (Figure 1). **Forests** represents native arboreal physiognomies, such as dense rainforest, lowland and swampy forests, and heterogeneous or homogeneous non-native formations (e.g. Eucalyptus plantations) with native understory vegetation. **Isolated Trees and small woods** represent mostly urban green cover outside protected areas and small woods, such as street afforestation, gardens, squares and urban parks with trees, but mostly without understory vegetation. **Open Vegetation** comprises shrubs and herbaceous vegetation, grasslands (natural and non-natural) and agricultural areas. We also used a georeferenced data of street trees for the entire city. In our analyses, we considered four explanatory variables related to the landscape composition: the cover of the three vegetation classes, and the density of street trees (numbers of trees divided by the area of each district). Those variables were obtained through data processing on the ArcGIS (v 10.8). The vegetation data, and other geographic information, such as municipality administrative limits, urban infrastructure and others, are available on GeoSampa portal (São Paulo, 2020).

Land sharing and sparing analysis

Based on Stott *el al.* (2015), we used an Enhanced Vegetation Index (EVI) image to create four land sharing and a land sparing indices. EVI values were obtained with a LANDSAT 8 image (30 m resolution), dated from April 2016 (one of three year of the hospitalizations data), that covers the entire city of São Paulo in the same day without any cloud cover. This image allowed a direct comparison of the districts without day, weather or seasonal variations on the image.

We first divided the histogram with EVI values in three quantiles (Figures 2 and S1): intermediate values correspond to cells with a mix of vegetation and buildings, low values represent mostly build-up areas, and high values correspond mostly to green and forestry areas. Proposed land sharing and land sparing indices are based on rations between these quantiles (Table 2), as presented below. We excluded EVI values lower than zero, because they mainly represent water. We also excluded cells that are located in open areas (e.g. grasslands, small fields), since those cells have intermediated values of EVI and can be mistaken with land sharing conditions (see below). As a consequence, in this study, land sharing and sparing indices consider only the spatial distribution of arboreal vegetation, and not all green areas in the city.

Determining the quantiles - To determine the three quantiles we evaluated the values distribution of the entire city, and used a sample of 10,000 cells to apply two thresholds. The first threshold represents the mean and standard deviation of urban areas (EVI = 0.16 ± 0.11) and the second one is the mean and standard deviation of the sample of green areas (EVI= 0.56 ± 0.11). With these two thresholds, we got the three quantiles, A, B and C, with A representing areas dominated by buildings (urban areas), B mixed areas and C arboreal green areas (Figure 2).

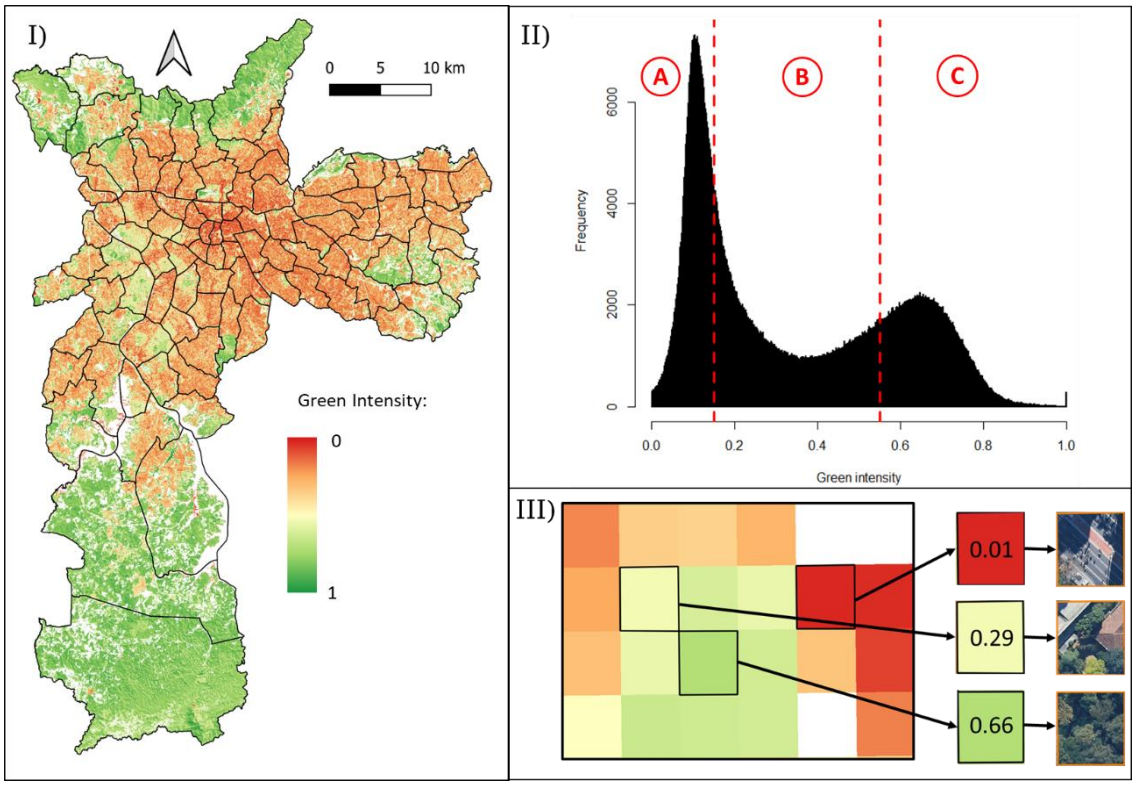

Figure 2 – EVI data and quantiles used to calculate land sharing and sparing indices. I) EVI image for São Paulo city, without water and open areas (both represented in white); II) Distribution of EVI values and thresholds – red dashed lines – establishing the three quantiles: A – Urban areas; B – Mixed areas and C – Green areas; III) A sample of the EVI image - LANDSAT 8 image representing all features into the 30 m pixels. When we have a pixel without any green we have a low EVI, on the other hand, pixels composed only by trees represents a high value of EVI. Mixed areas with green and urban have an intermediate value.

For a given region composed of a set of cells with EVI values, land sharing and land sparing patterns can be inferred based on the frequency of cells in different green intensity (Soga et al, 2014). A single central peak in the intermediary values represents a land sharing pattern, because intermediary values are related to mixed regions with green and urban infrastructure (Figure 3-A, B). On the other side, a bimodal distribution, with one peak in low values of EVI (high presence of urban areas) and another peak on high values of EVI represents a land sparing pattern (Figure 3-D). Land sharing and land

sparing in this approach is a continuous gradient, with intermediate situations, that are not land sharing neither land sparing, nor even both occurring at the same time (Figure 3-C).

Calculating the land sharing and land sparing indices: To consider a landscape as a sharing area we need to have some degree of mixture in terms of green and non-green, that can be easily identified observing the proportion values on the B portion of the histogram, which is represented by the **Sharing Vegetation Index (SVI) (**Table 2). On the other hand, it is more complicated to assume a degree of land sparing, requiring more than one metric to evaluate it, depending on the evenness and unevenness in the quantities between the green pixels and urban pixels, as illustrated in Figure 3.

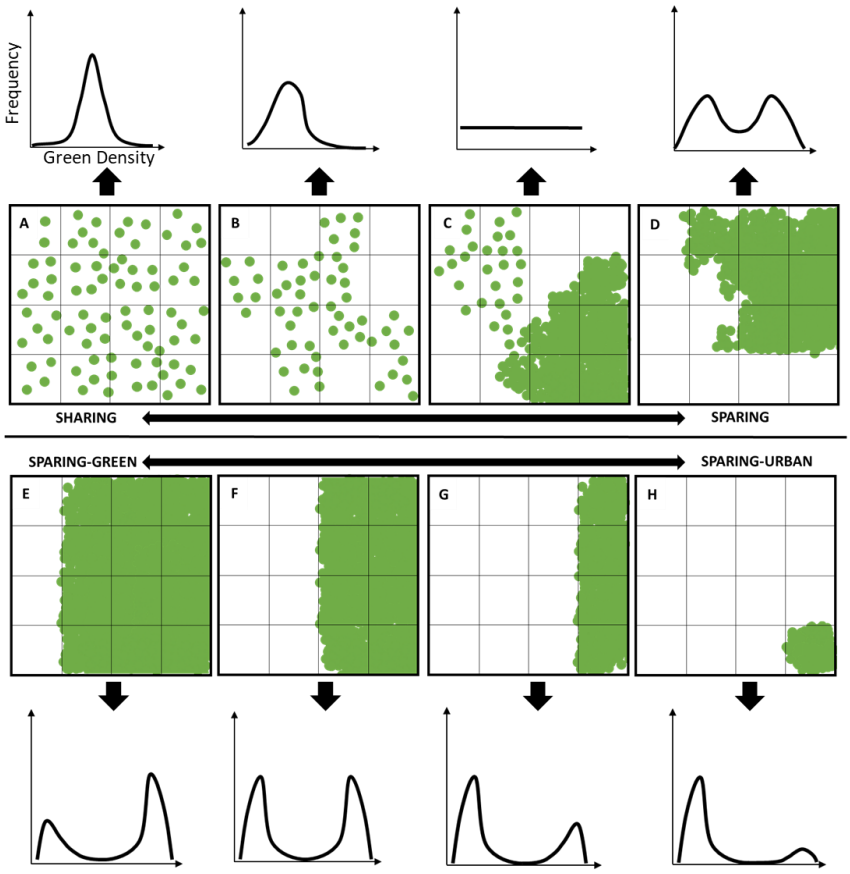

Figure 3 – Land sharing and sparing patterns, defined by sharing/sparing level and evenness between green and built areas. The first four examples (A to D) represent a gradient of landscapes from sharing (one central peak on EVI distribution) to sparing (two peaks separated by a valley on the EVI distribution) patterns. At intermediate conditions, no clear sharing and sparing pattern appears (C). The following examples (E to H) represent different land sparing conditions within a continuous gradient in terms of evenness, from sparing green (E) – where the majority of pixels are green – to a sparing urban – where the majority of pixels are gray, i.e. housing or built areas (H).

We evaluate the land sparing in three terms: (1) green level of sparing– **Sparing Green Vegetation Index (SGVI)**; (2) urban level of sparing – **Sparing Urban Vegetation Index (SUVI)**; and (3) how even are the distribution between them – **Sparing**

Unevenness Vegetation Index (SEVI). The methodology is an adaptation of ideas described by other authors (Soga et al., 2014; Stott et al., 2015) and developed to allow a statistical analysis. We applied this methodology for the 96 districts of São Paulo City, assuming that a typical sharing index can be found when all the cells are in the B quantile and sparing when all cells are distributed between quantiles A and C (Figure 3). For the estimation of quantiles and proportion of pixels in each quantile, we used R (v. 3.5.3) with the packages *raster*, *rgdal* and *bbmle*.

Table 1 – Land sharing and sparing indices and formulas. A, B and C represents the number of pixels in each quantile of the EVI histogram (Figure 2II).

Name	**Formula**	**Description**
Sharing Vegetation Index	$SVI = \frac{B}{A + B + C}$	Proportion (varying from 0 to 1) in the whole landscape of pixels with values in B quantile, representing the level of land sharing
Sparing-Green Vegetation Index	$SGVI = \frac{C}{A + B + C}$	Proportion (varying from 0 to 1) in the whole landscape of pixels with values in quantile C – sparing with high green density.
Sparing-Urban Vegetation Index	$SUVI = \frac{A}{A + B + C}$	Proportion (varying from 0 to 1) in the whole landscape of pixels with values in quantile A – sparing with high urban density
Sparing-Unevenness Vegetation Index	$SEVI = \left\lvert \frac{A - C}{A + C} \right\rvert$	Absolute normalized difference between quantiles A and C, representing the unevenness between green and urban areas, varying from zero to one with low values representing sparing conditions with more even contributions of green and urban areas.

Box 1 – Districts of São Paulo city with contrasting land sharing and sparing patterns

Morumbi district (Figure Box 1), in southwest region of São Paulo City, is an example of land sharing region. Mostly of EVI values are into quantile B of the histogram, representing a mixed of urban and green areas. On the satellite image it is possible to notice the high quantity of vegetation in between the buildings. *Grajaú district* (Figure Box 2), in the southeast portion of São Paulo City, represents an example of a typical land sparing pattern. On this region exists a well-established region of urbanization just close to areas of forest remnants, with low mixture between those regions. In that way, most of the pixels' values of EVI are concentrated in A and C quantiles. The white areas in both figures correspond to water and open areas, removed from analysis. In sparing example, we have a intermediate evenness between quantiles A and C, resulting in a medium value of the Sparing-Unevenness Vegetation – Index (SEVI).

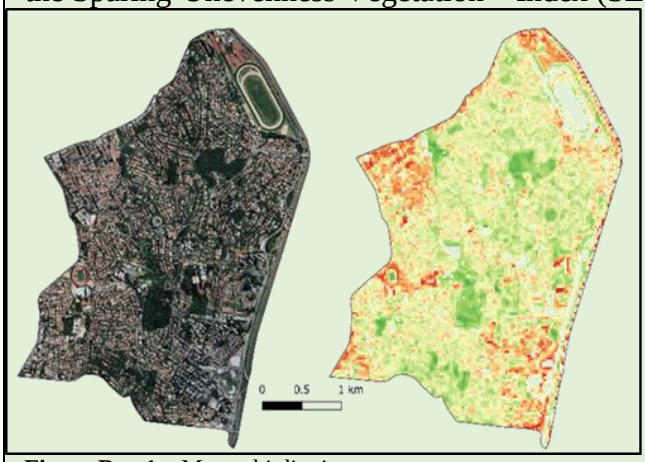

Figure Box 1 – Morumbi district.

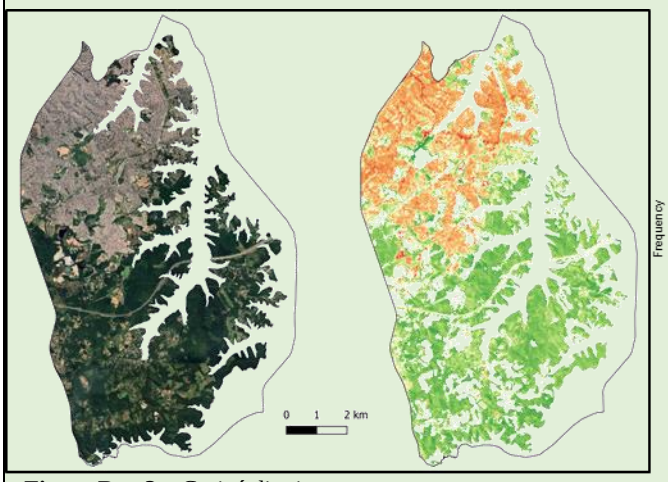

Figure Box 2 – Grajaú district.

	SVI	SGVI	SUVI	SEVI
Morumbi	0.815	0.069	0.116	0.257
Grajaú	0.337	0.488	0.176	0.470

Table box 1 – The four indices for Morumbi and Grajaú examples. SVI – Sharing vegetation index; SGVI – Sparing-green vegetation index; SUVI – Sparing-urban vegetation index; SEVI – Sparing unevenness vegetation index.

Statistical analysis

We investigated how hospitalization rates of cardiovascular, superior and inferior respiratory diseases respond for different green quantity, vegetation types and green distribution with *Generalized Linear Models* (GLM). Models were constructed in R, using the *binomial* family (Richardson et al., 2015). Our response variable was a "rate of hospitalization", defined by the ration between the number of hospitalizations in each of the 96 districts, for each of the three diseases groups (Table S1), in relation to the estimated number of SUS users in each district minus the number of hospitalizations. We used the function *cbind* (base R package 3.6) to construct a matrix of success (number of hospitalizations) and non-success (number of SUS users minus number of hospitalizations). The predictive variables were the four sharing and sparing indices (SVI, SUVI, SGI and SEVI; Table 2), the proportions of forests (5), isolated trees and small woods (6), and open vegetation (7), the total arboreal cover (Forests + Isolated Trees and Small Woods) (8); the total green cover (forests + isolated trees + open vegetation) (9); and the density of street trees points in each district (10). For all models we used the GeoSES index for the district as a co-variable, building additive multiple GLM. We also made additive models combining pairs of landscape variables with less than 70% of correlation between them (Table S2). All landscape values vary from zero to one and the GeoSES score varies from minus one to one. We built a null model – response variables adjusted to 1 – to test the null hypothesis. We present the analyses considering all years and seasons together, but we also did the same analyses considering separated years and the four seasons – Summer from January to March; Autumn from April to June; Winter July to September; Spring from October to December. As there was no significant difference in the number of hospitalizations between the seasons and the years and the response patterns are very similar (see supplementary material), we present and discuss the results with all data together.

We selected the best model by *Akaike Information Criteria* (AIC, Burnham & Anderson, 2002). We considered the models equally plausible if the $\Delta AIC \leq 2$, and best model was the one with the lowest value of AIC.

Box 2 – Districts of São Paulo city with different sparing conditions

Sparing conditions can be observed with different unevenness conditions, at times dominated by green areas, and at other times by urban areas.

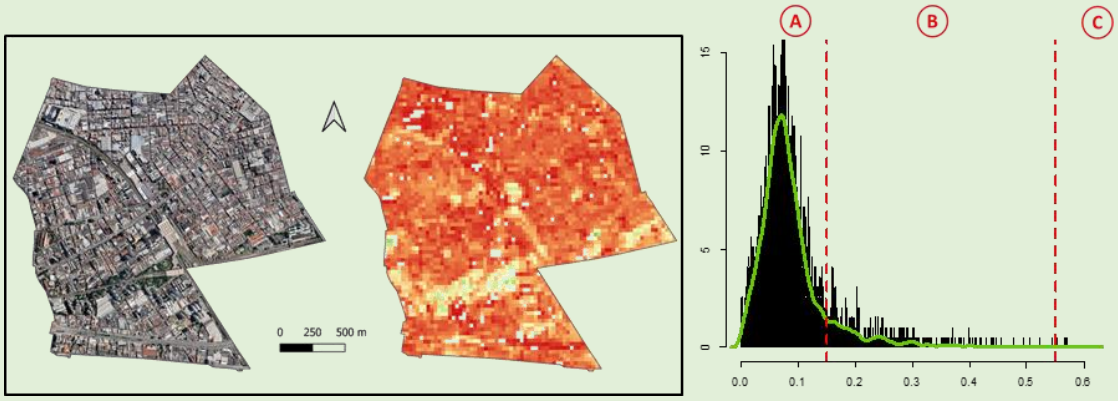

Figure Box 3 – *Brás* district.

Brás district, in the center of São Paulo city (Figure Box 3), is a high urbanized region, with most of EVI pixel values in quantile A, representing a high level or Sparing-Urban Vegetation Index (SUVI), with high level of unevenness between green and gray, represented by SEVI. *Marsilac* district (Figure Box 4), in the far south of São Paulo municipality, is predominantly forested (quantile C) and protect by Atlantic Rainforest nature reserves. This is a highly vegetated region with a low urbanization level.

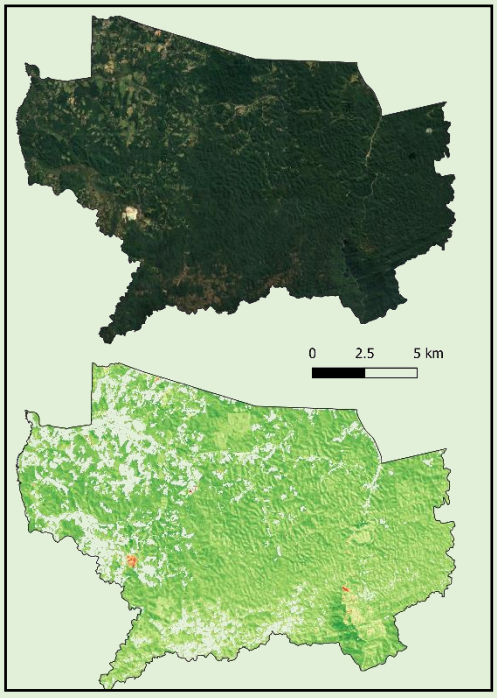

Figure Box 4 – *Marsilac* district

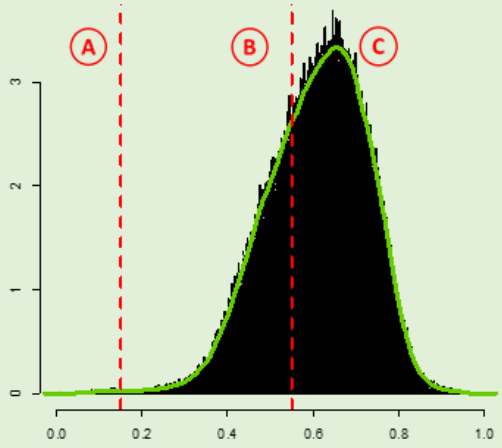

Table box 2 – The four indexes for *Brás* and *Marsilac* examples. SVI – Sharing vegetation index; SGVI – Sparing-green vegetation index; SUVI – Sparing-urban vegetation index; SEVI – Sparing unevenness vegetation

	SVI	SGVI	SUVI	SEVI
Brás	0.112	0.001	0.886	0.999
Marsilac	0.298	0.700	0.002	0.993

RESULTS

From 2014 to 2016, 32,726 hospitalizations were registered for cardiovascular causes, 766 for superior respiratory system causes and 1,828 for inferior respiratory system causes, considering adults with 20 years or the diseases codes presented in Table S1. These hospitalizations are unevenly distributed across the city of São Paulo, with a tendency for higher rates in marginal areas of the city (Figure 4 A, B, C). All rates presented high standard deviations, suggesting that the districts and regions of São Paulo city are highly different in terms of hospitalization rates, as it is in terms of socioeconomic conditions and SUS users (Figure 1).

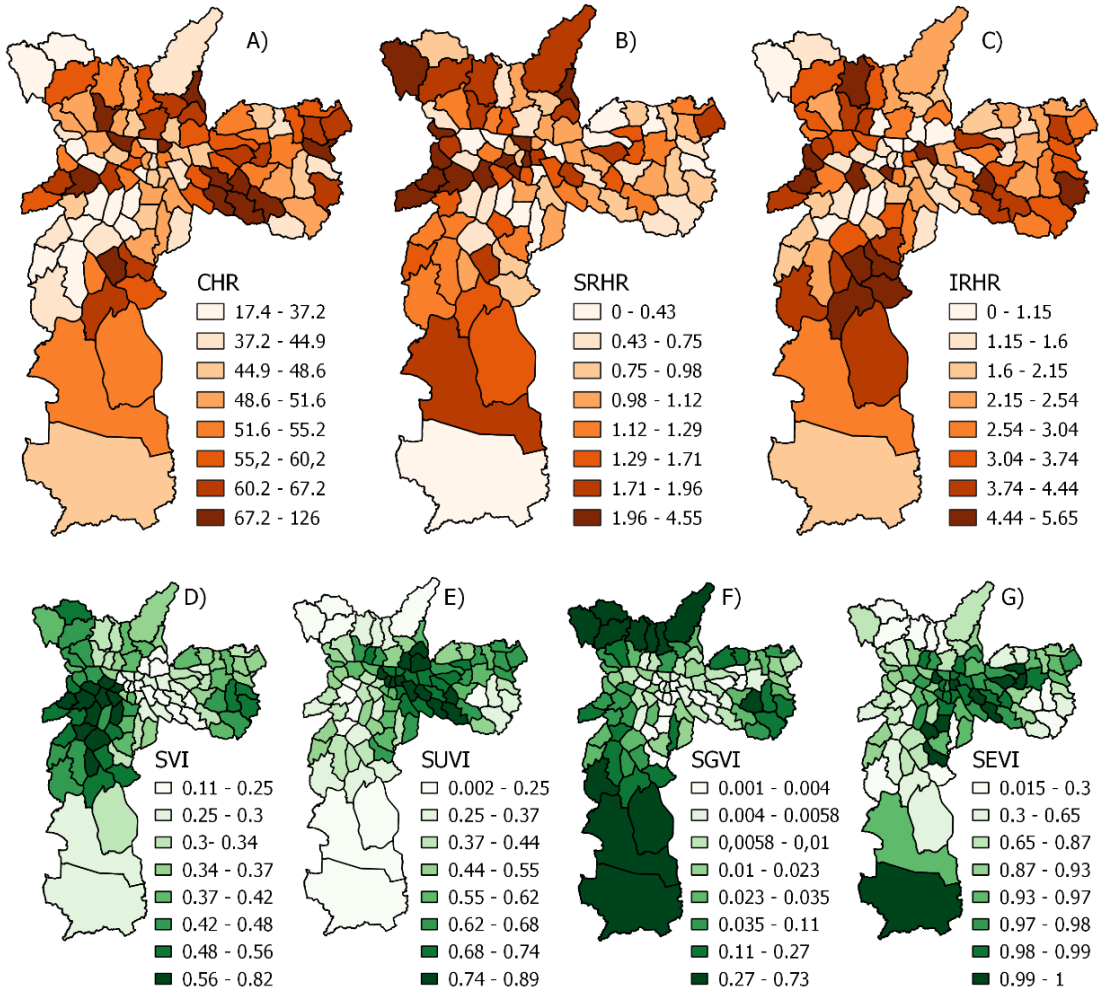

Figure 4– The distribution of hospitalizations per 10,000 SUS's users in the districts and sharing and sparing indices. A) Cardiovascular Hospitalization Rate (CHR); B) Superior respiratory hospitalization rate (SRHR); C) Inferior respiratory hospitalization rate (IRHR); D) Sharing Vegetation Index (SVI); E) Sparing Urban Vegetation index (SUVI); F) Sparing Green Vegetation Index (SGVI); G) Sparing Unevenness Vegetation Index (SEVI).

The model selection resulted in different set of explanatory variables for each disease group (Table 2, Figure 5). For cardiovascular diseases only one model was selected,

showing a negative effect of both total arboreal cover and the sharing index on hospitalization rate. For superior respiratory diseases, three models were selected, all having a negative relationship between open vegetation areas and hospitalization rates, and also including a positive effect of sparing green and forests, and a negative effect of sparing urban. For inferior respiratory diseases, one of the best models shows a decrease in the hospitalization rate with the increment of isolated trees and small woods, and also with an increase in sparing unevenness.

Table 2 –Best models selected for each disease group. AICc is the Akaike Information Criteria corrected; ΔAIC is the distance of AIC that the models are to the first; df are the degrees of freedom; weight represents the strength of model in relation to the others. Only the models with dAICc ≤ 2 are presented. The estimate is the value non-transformed (logit link binomial glm) of the size of effect for each variable.

Model	AICc	ΔAIC	df	weight	estimate	sd	p-value
CARDIOVASCULAR							
Total Arboreal Cover +					-0.30975	0.0393	<0.001
Sharing	2377.5	0	4	0.9953	-0.83377	0.05423	< 0.001
GeoSES					-0.03740	0.01678	0.0259
SUPERIOR RESPIRATORY							
Open Vegetation +					-2.46005	0.86407	0.00441
Sparing Urban	580.5	0	4	0.2385	-0.67905	0.23072	0.00325
GeoSES					-0.1080	0.1209	0.37145
Open Vegetation +					-1.88944	0.77028	0.01417
Sparing Green	580.9	0.4	4	0.198	0.75036	0.25677	0.00347
GeoSES					0.04389	0.12519	0.72589
Open Vegetation +					-1.43535	0.71185	0.04376
Forests	582.5	2	4	0.0873	0.67752	0.25709	0.00841
GeoSES					0.02862	0.12515	0.81911
INFERIOR RESPIRATORY							
Isolated Trees and Small Woods +					-1.795	0.6562	0.00623
Sparing Unevenness	765.2	0	4	0.7117	-0.37	0.1665	0.02627
GeoSES					-0.10993	0.09285	0.23639

DISCUSSION

We found consistent patterns that relate the reduction of cardiovascular and respiratory disease in urban environments to green areas, considering not only the quantity, but also their spatial distribution and the type of those areas. In an innovative way, we have shown that hospitalization rates for cardiovascular diseases are more related to the distribution than to amount of green or arboreal areas, with a land sharing pattern favoring the reduction of those diseases. On the other hand, land sparing pattern was

more relevant in reducing superior respiratory diseases. In this case, there was also a positive effect of green (the more green, the more hospitalizations) and a negative effect of urban areas. There is thus a tradeoff regarding the effect of green areas and sparing/sharing configuration for cardiovascular and superior respiratory disease. For inferior respiratory disease, the main effect is related to isolated trees and small woods – districts with higher tree density are less prone to present high rates of diseases.

Land sharing districts have a lower frequency of cardiovascular diseases, with an increase of each 10% of sharing level corresponding to a decrease of 8% on hospitalization rates by cardiovascular outcomes in the population. This effect occurs after controlling for socio-economic variations, which are very evident in the city of São Paulo. Richest districts have high levels of land sharing, higher availability of parks and green areas and high tree cover along streets, while poorer districts with dense population have less street trees and low availability of green between the households. This pattern can be noticed in the entire Latin America, indicating a greater social inequality due to the lack of adequate urban planning (Dobbs et al., 2018). On the other hand, marginal regions of the city of São Paulo have more areas with dense green coverage, composed by forest remnants, but in most case those areas do not have visitation access or are dangerous places, resulting in little use of the space for recreation and leisure activities. As a consequence, besides the socio-economic conditions being worse in marginal areas, access to green areas is more limited, which could be related with higher hospitalization rates.

The importance of land sharing design can be explained by a wider spatial distribution of ecosystem services that benefit people's health, thereby bringing the service supply closer to those who demand it (Metzger et al., 2020). Services such as scenic view, tree shading, noise control, heat control and also other recreational and cultural activities are services that have been proven to provide improved protection against human diseases (Coutts & Hahn, 2015; Kabisch et al., 2017; Roe et al., 2013; Sandifer et al., 2015). All those services are provided in areas close to the green areas. The proximity between demand areas (in this case, inhabited areas) and supply areas is thus a crucial factor for those ecosystem service provision, being this proximity favored by a sharing configuration. Regions of the city with land sharing patterns represents more beautiful landscapes given by well-maintained gardens and green areas, and also street trees.

Furthermore, the proximity to green areas should also increase the frequency and intensity of use of those areas, by providing pleasant environments to walk, sport practices, gardening and other outdoor activities in the neighborhood (Dennis & James, 2016; Samuelsson et al., 2018; Soga et al., 2017), resulting thus in higher "nature doses" (Shanahan et al., 2015). Within a land sharing design, all those benefits from green areas are provided more homogenously in space, positively influencing a larger portion of the inhabitants of the cities or increasing the exposure and experience of nature (Bratman et al., 2019; Marselle et al., 2020).

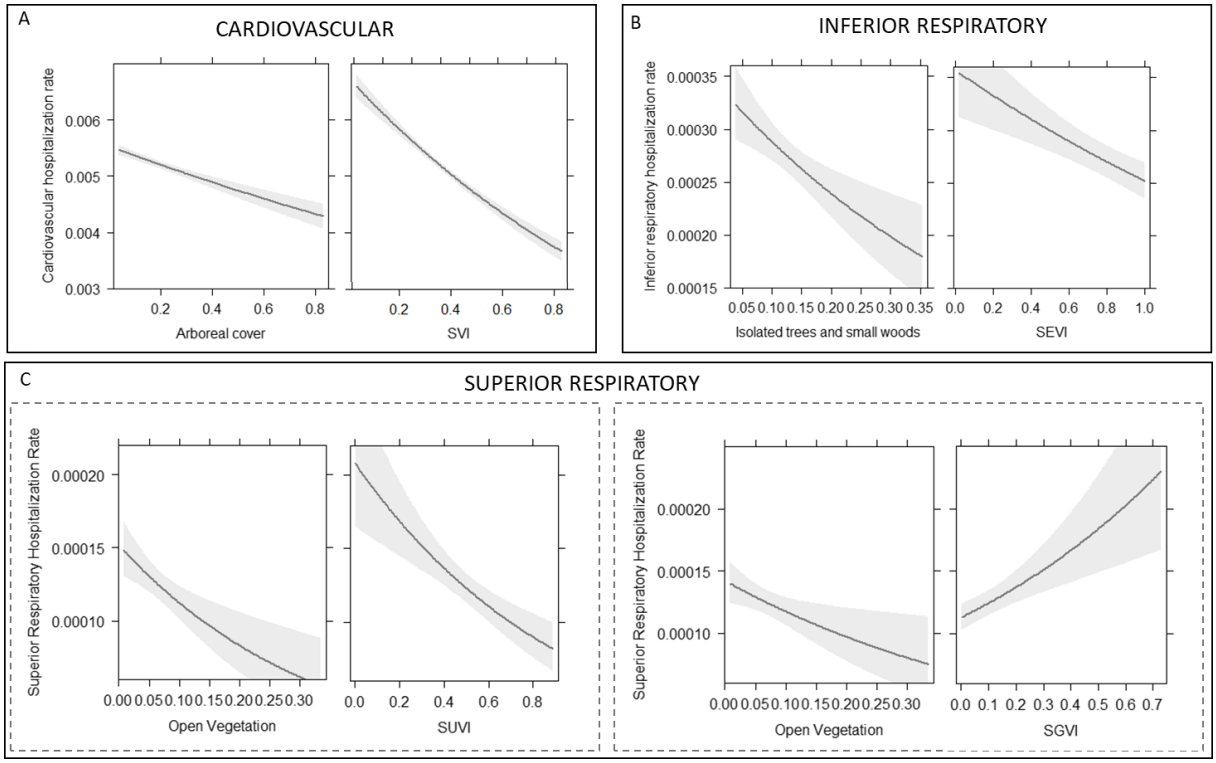

Figure 5 – Effect plots of the best models selected by AIC for each group of diseases. Cardiovascular (A); Inferior Respiratory (B) and Superior Respiratory (C). For superior respiratory diseases the graphics represents the two best models.

On the other hand, for superior respiratory diseases we found an opposite effect of green areas, and also of sparing green configuration, showing a potential disservice of those areas. According to the selected models, the increase of 10% of sparing green level increases 10% of hospitalization risk, and the increase of 10% in forest cover increases 9% of hospitalization risk. The diseases selected in superior respiratory health category (Table S1 – suplementary material) are all related with potential respiratory allergies, which can be caused by higher humidity, air pollen, fungus and mites in regions nearby forests (Parmes et al., 2020). Little is known about pollen and allergies on tropical environments (Caraballo et al., 2016; Johnston et al., 2009), but in temperate climates

the relationships between proximity of forest environments and respiratory allergies are better established (Parmes et al., 2020). This potential explanation is reinforced by the fact that hospitalizations for superior respiratory causes were higher in spring (Figure S2 – supplementary material), when there are more pollen particles in air and still a humid weather, favoring the increase of organisms like mites and fungus that can cause allergies. Conversely, an increment of 10% of open vegetation and urban areas reduces the hospitalization risk in 25 and 10%, respectively, which can be related to the higher insolation and less favorable environments for development of fungus and mites, having a lower presence of them by the lack of forests (Dudek et al., 2018; Parmes et al., 2020). In that way, forests can represent a disservice on human health in terms of allergies, (Dudek et al., 2018), and open vegetation and urban areas a service, but these relationships still lack stronger scientific evidence, especially in the tropics.

Although forests have negative effects on superior respiratory health, on inferior respiratory health they have a positive effect, with 10% of increment on urban woods representing a 17% decrease in hospitalization risk on inferior respiratory diseases. In landscapes with high green coverage, mainly with urban parks, urban reserves and squares with tree coverage, the rate of hospitalizations by lung-related diseases decreases. Similarly to what was observed for cardiovascular diseases, the better spatial distribution of green areas, even in the form of isolated trees or small woods, seems to favor disease prevention. Tree cover and small woods (as urban parks and forests) can play a role in the air quality control (Janhäll, 2015), what can be related on the control of lung diseases. Those areas can also offer cultural ecosystem services, stimulating sporting practices and recreational activities, what can in long-term also benefit lung health. In the scale of districts, the land sparing with more contribution of green than urban areas seem to be important to decrease the rate of inferior respiratory diseases, showing the importance of maintaining dense and green areas, as small woods on the control of lung-related diseases (Figure 5-B).

Forest and green areas can thus have contrasting effects, at times providing a service (for cardiovascular and inferior respiratory diseases), at others a disservice (for superior respiratory diseases). However, services provided by green areas affect diseases that are more frequent and more serious than those that can be strengthened by forests (superior respiratory ones). On average, there are 13,184 hospitalizations by year of adults on

public system by diseases that can be controlled by green coverage (cardiovascular and inferior respiratory), and just 255 for superior respiratory. In that way, the services of green areas are proportionally greater than the disservices for human health.

Our results suggest that the best configuration between land sharing and land sparing depends on the type of diseases and the amount of green coverage available. A high green coverage distributed in a land sharing pattern may propitiate a higher opportunity for people to be in contact with green areas, enhancing cultural ecosystem services. In other hand, in more urbanized conditions, a land sparing pattern may provide regulating services, but people do not always have access to green areas or that access is safe. The best configuration is when we have high total green coverage, distributed in the landscape with dense green patches (safe parks and protected areas) but also with street afforestation and small urban woods in between the households. This configuration is more likely a land sharing pattern, but with the maintenance of some dense regions (See box 1, *Morumbi* district). In that way, well maintained vegetation in between the urban network plays a key-role on population health and well-being, probably through a better sense of place, outdoor activities stimulation and stress control, but also in the control of environmental conditions by dense forests. In terms of land sharing and sparing, regions with high levels of cardiovascular outcomes need more green areas in between the households. Additionally, denser and well established arboreal vegetation into the urban region are needed to reduce the chances of inferior respiratory hospitalizations.

Implications for Urban-planning and Decision-makers

In general, the health benefits provided by green areas, more intensively propitiated by land sharing configurations (compared to land sparing ones), seem to be greater than eventual disservices, and could thus be used in the planning of healthier urban landscapes. Increasing land sharing seems to be an interesting target for urban planning in order to provide a more even spatial distribution of ecosystem services, and prevent the occurrence of some diseases, particularly in the case of cardiovascular disease. Decision makers should thus improve the distribution and coverage of green in the city (de Groot et al., 2010).

Enabling the provision of ecosystem services through nature-based solutions (Cohen-Shacham et al., 2019) is a powerful tool to increase health quality of citizens, alleviating

some of the problems of urban life (Bush & Doyon, 2019). Land sharing configuration is part of these solutions. The land sharing indicator is not only related with the density of street trees in the district ($R=0.4$; $p<0.001$), but also with the vegetation compound by isolated trees and small urban woods ($R=0.8$; $p<0.001$). To increase land sharing, we should stimulate the creation or recovery of green areas, both in public and private areas, including the expansion of street afforestation, the creation of public squares, the establishment of gardens and trees inside private land – all those actions can help to increase land sharing and making cities greener (Miller & Montalto, 2019).

The solutions based on nature should prioritize regions with less social resources, and which are composed by large amount of public health system users. Those regions are mostly situated at the city periphery, and usually they lack green areas or have green areas in a sparing configuration, but with restricted or dangerous access. Creating parks is not enough – existing parks need to be safer and more suitable for use, in addition to the development of projects focused in increase the density of trees in streets.

As some regions of the cities have low availability of land to implement new green areas, nature-based solutions should focus in the multiplication of small initiatives, as planting trees on small spaces, like central avenue bed, sidewalks and street traffic circles, the implementation of green roofs and facades, and bioswale (Miller & Montalto, 2019). The sum of these small lots in the middle of urbanized regions matter to improve the total green cover, increasing land sharing intensity, and thus spreading ecosystem services supply nearby who demands it.

The regulation of human health through the expansion of green areas and land sharing configuration using nature-based solutions can improve the quality of life and health of people in cities (van den Bosch & Ode Sang, 2017). These can both save health costs and provide long-term solutions, if those solutions are perpetuated in the landscape and used by several generations of city dwellers.

CONCLUSIONS

Not just the amount, but also the type and distribution of green coverage matters to prevent cardiovascular, superior respiratory and inferior respiratory diseases. Land sharing configuration has proved relevant to prevent cardiovascular system

hospitalization rates, probably by providing greater exposure to and usufruct of regulating and cultural ecosystem services that act on human health. The amount of dense tree canopy reduces cardiovascular and inferior respiratory hospitalization rates, but potentially increase allergies hospitalizations. In general lines, the services provided by forests and urban woods on human health, particularly a land sharing configuration, are bigger than their disservices. Thus, the increase of green areas and the intensification of sharing configuration are relevant targets for urban planning, in particular through multiple small projects of nature-based solutions scattered throughout the urban landscape. Those solutions can be more efficient, cheaper and lasting, since the urban green remain for generations on urban landscape, and can benefit the population in the long term.

REFERENCES

Alcock, I., White, M., Cherrie, M., Wheeler, B., Taylor, J., McInnes, R., … Fleming, L. (2017). Land cover and air pollution are associated with asthma hospitalisations: A cross-sectional study. Environment International, 109, 29–41. doi: 10.1016/j.envint.2017.08.009

Almeida, C. M. V. B., Mariano, M. V., Agostinho, F., Liu, G. Y., Yang, Z. F., Coscieme, L., & Giannetti, B. F. (2018). Comparing costs and supply of supporting and regulating services provided by urban parks at different spatial scales. Ecosystem Services, 30, 236–247. doi: 10.1016/j.ecoser.2017.07.003

Astell-Burt, T., & Feng, X. (2020). Urban green space, tree canopy and prevention of cardiometabolic diseases: a multilevel longitudinal study of 46 786 Australians. International Journal of Epidemiology, 49(3), 926–933. doi: 10.1093/ije/dyz239

Balmford, A., Green, R., & Phalan, B. (2012). What conservationists need to know about farming. Proceedings of the Royal Society B: Biological Sciences, 279(1739), 2714–2724. doi: 10.1098/rspb.2012.0515

Barrozo, L. V., Fornaciali, M., de André, C. D. S., Morais, G. A. Z., Mansur, G., Cabral-Miranda, W., … Júnior, E. A. (2019). GeoSES -- um Índice Socioeconômico para Estudos de Saúde no Brasil. ArXiv. Retrieved from http://arxiv.org/abs/1910.06155

Bratman, G. N., Anderson, C. B., Berman, M. G., Cochran, B., de Vries, S., Flanders, J., … Daily, G. C. (2019). Nature and mental health: An ecosystem service perspective. Science Advances, Vol. 5, pp. 903–927. American Association for the Advancement of Science. doi: 10.1126/sciadv.aax0903

Burnham, K. P., & Anderson, D. R. (2002). A practical information-theoretic approach. Model selection and multimodel inference, 2.

Bush, J., & Doyon, A. (2019). Building urban resilience with nature-based solutions: How can urban planning contribute? Cities, 95, 102483. doi: 10.1016/j.cities.2019.102483

Caraballo, L., Zakzuk, J., Lee, B. W., Acevedo, N., Soh, J. Y., Sánchez-Borges, M., … Cardona, V. (2016, June 27). Particularities of allergy in the Tropics. World Allergy Organization Journal, Vol. 9, pp. 1–44. BioMed Central Ltd. doi: 10.1186/s40413-016-0110-7

CEINFO, Coordenação de Epidemiologia e Informação. Estimativa da população exclusivamente usuária SUS no Município de São Paulo. Boletim Eletrônico CEINFO. n.1 y. 1, 2010. Avilable in: <https://www.prefeitura.sp.gov.br/cidade/secretarias/upload/saude/arquivos/boletimeletronico/n01popsus.pdf>

CEM. Dicionário da Base de dados geocodificados das Autorizações das Internações Hospitalares no município de São Paulo, 2000 a 2016. Centro de Estudos da Metrópole, CEBRAP: São Paulo, 2017.

CEM, Centro de Estudos da Metrópole – Download de dados. Available in: <https://centrodametropole.fflch.usp.br/pt-br/download-de-dados> Last accessed in: 04th May 2021.

Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., … Walters, G. (2019, August 1). Core principles for successfully implementing and upscaling Nature-based Solutions. Environmental Science and Policy, Vol. 98, pp. 20–29. Elsevier Ltd. doi: 10.1016/j.envsci.2019.04.014

Coutts, C., & Hahn, M. (2015, August 18). Green infrastructure, ecosystem services, and human health. International Journal of Environmental Research and Public Health, Vol. 12, pp. 9768–9798. MDPI AG. doi: 10.3390/ijerph120809768

de Groot, R. S., Alkemade, R., Braat, L., Hein, L., & Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity, 7(3), 260–272. doi: 10.1016/j.ecocom.2009.10.006

Dennis, M., & James, P. (2016). Site-specific factors in the production of local urban ecosystem services: A case study of community-managed green space. Ecosystem Services, 17, 208–216. doi: 10.1016/j.ecoser.2016.01.003

Dobbs, C., Hernández-Moreno, Á., Reyes-Paecke, S., & Miranda, M. D. (2018). Exploring temporal dynamics of urban ecosystem services in Latin America: The case of Bogota (Colombia) and Santiago (Chile). Ecological Indicators, 85, 1068–1080. doi: 10.1016/j.ecolind.2017.11.062

Dudek, T., Kasprzyk, I., & Dulska-Jeż, A. (2018). Forest as a place for recreation but also the source of allergenic plant pollen: to come or avoid? European Journal of Forest Research, 137(6), 849–862. doi: 10.1007/s10342-018-1144-x

Ferrante, G., Asta, F., Cilluffo, G., De Sario, M., Michelozzi, P., & La Grutta, S. (2020). The effect of residential urban greenness on allergic respiratory diseases in youth: A narrative review. World Allergy Organization Journal, 13(1), 100096. doi: 10.1016/j.waojou.2019.100096

Hegetschweiler, K. T., de Vries, S., Arnberger, A., Bell, S., Brennan, M., Siter, N., … Hunziker, M. (2017, January 1). Linking demand and supply factors in identifying cultural ecosystem services of urban green infrastructures: A review of European studies. Urban Forestry and Urban Greening, Vol. 21, pp. 48–59. Elsevier GmbH. doi: 10.1016/j.ufug.2016.11.002

IBGE – Instituto Brasileiro de Geografia e Estatística. (2010). Censo Brasileiro de 2010. Available in: < https://censo2010.ibge.gov.br/> Last accessed in: 14th May 2021.

IBGE – Instituto Brasileiro de Geografia e Estatística. (2021). Cidades e Estados. Available in: < https://www.ibge.gov.br/cidades-e-estados/sp/sao-paulo.html?> Last accessed in: 14th May 2021.

James, P., Banay, R. F., Hart, J. E., & Laden, F. (2015). A Review of the Health Benefits of Greenness. Current Epidemiology Reports, 2(2), 131–142. doi: 10.1007/s40471-015-0043-7

Janhäll, S. (2015, March 1). Review on urban vegetation and particle air pollution - Deposition and dispersion. Atmospheric Environment, Vol. 105, pp. 130–137. Elsevier Ltd. doi: 10.1016/j.atmosenv.2015.01.052

Jennings, V., & Gaither, C. J. (2015). Approaching environmental health disparities and green spaces: An ecosystem services perspective. International Journal of Environmental Research and Public Health, 12(2), 1952–1968. doi: 10.3390/ijerph120201952

Johnston, F. H., Hanigan, I. C., & Bowman, D. M. J. S. (2009). Pollen loads and allergic rhinitis in darwin, australia: A potential health outcome of the grass-fire cycle. EcoHealth, 6(1), 99–108. doi: 10.1007/s10393-009-0225-1

Kabisch, N., van den Bosch, M., & Lafortezza, R. (2017). The health benefits of nature-based solutions to urbanization challenges for children and the elderly – A systematic review. Environmental Research, 159, 362–373. doi: 10.1016/j.envres.2017.08.004

Kaczynski, A. T., Besenyi, G. M., Stanis, S. W. A., Koohsari, M. J., Oestman, K. B., Bergstrom, R., … Reis, R. S. (2014). Are park proximity and park features related to park use and park-based physical activity among adults? Variations by multiple socio-demographic characteristics. International Journal of Behavioral Nutrition

and Physical Activity, 11(1), 146. doi: 10.1186/s12966-014-0146-4

Kondo, M. C., Fluehr, J. M., McKeon, T., & Branas, C. C. (2018, March 3). Urban green space and its impact on human health. International Journal of Environmental Research and Public Health, Vol. 15, p. 445. MDPI AG. doi: 10.3390/ijerph15030445

Kosanic, A., & Petzold, J. (2020, October 1). A systematic review of cultural ecosystem services and human wellbeing. Ecosystem Services, Vol. 45, p. 101168. Elsevier B.V. doi: 10.1016/j.ecoser.2020.101168

Lin, B. B., & Fuller, R. A. (2013). FORUM: Sharing or sparing? How should we grow the world's cities? Journal of Applied Ecology, 50(5), 1161–1168. doi: 10.1111/1365-2664.12118

Lotufo, P. A. (2017, January 1). Áreas verdes, ar puro e saúde cardiovascular na cidade de São Paulo. Sao Paulo Medical Journal, Vol. 135, pp. 1–3. Associacao Paulista de Medicina. doi: 10.1590/1516-3180.2017.1351291216

Marselle, M. R., Bowler, D. E., Watzema, J., Eichenberg, D., Kirsten, T., & Bonn, A. (2020). Urban street tree biodiversity and antidepressant prescriptions. Scientific Reports, 10(1), 1–11. doi: 10.1038/s41598-020-79924-5

Methorst, J., Bonn, A., Marselle, M., Böhning-Gaese, K., & Rehdanz, K. (2021). Species richness is positively related to mental health – A study for Germany. Landscape and Urban Planning, 211, 104084. doi: 10.1016/j.landurbplan.2021.104084

Metzger, J. P., Fidelman, P., Sattler, C., Schröter, B., Maron, M., Eigenbrod, F., … Rhodes, J. R. (2020). Connecting governance interventions to ecosystem services provision: A social-ecological network approach. People and Nature, 3(2), 266–280. doi: 10.1002/pan3.10172

Miller, S. M., & Montalto, F. A. (2019). Stakeholder perceptions of the ecosystem services provided by Green Infrastructure in New York City. Ecosystem Services, 37, 100928. doi: 10.1016/j.ecoser.2019.100928

Mitchell, M. G. E., Suarez-Castro, A. F., Martinez-Harms, M., Maron, M., McAlpine, C., Gaston, K. J., … Rhodes, J. R. (2015, April 1). Reframing landscape fragmentation's effects on ecosystem services. Trends in Ecology and Evolution, Vol. 30, pp. 190–198. Elsevier Ltd. doi: 10.1016/j.tree.2015.01.011

Moreira, T. C. L., Polizel, J. L., Santos, I. de S., Silva Filho, D. F., Bensenor, I., Lotufo, P. A., & Mauad, T. (2020). Green spaces, land cover, street trees and hypertension in the megacity of são paulo. International Journal of Environmental Research and Public Health, 17(3). doi: 10.3390/ijerph17030725

Nieuwenhuijsen, M. J., Khreis, H., Triguero-Mas, M., Gascon, M., & Dadvand, P.

(2017, January 1). Fifty shades of green. Epidemiology, Vol. 28, pp. 63–71. Lippincott Williams and Wilkins. doi: 10.1097/EDE.0000000000000549

ONU - United Nations, Department of Economic and Social Affairs (2017), Population Division. World Population Prospects: The 2017 Revision. V.1

ONU - United Nations, Department of Economic and Social Affairs (2018), Population Division. World Urbanization Prospects: The 2018 Revision

Parmes, E., Pesce, G., Sabel, C. E., Baldacci, S., Bono, R., Brescianini, S., … Annesi-Maesano, I. (2020). Influence of residential land cover on childhood allergic and respiratory symptoms and diseases: Evidence from 9 European cohorts. Environmental Research, 183, 108953. doi: 10.1016/j.envres.2019.108953

Plans, E., Gullón, P., Cebrecos, A., Fontán, M., Díez, J., Nieuwenhuijsen, M., & Franco, M. (2019). Density of green spaces and cardiovascular risk factors in the city of madrid: The heart healthy hoods study. International Journal of Environmental Research and Public Health, 16(24). doi: 10.3390/ijerph16244918

Rezende, C. L., Scarano, F. R., Assad, E. D., Joly, C. A., Metzger, J. P., Strassburg, B. B. N., … Mittermeier, R. A. (2018). From hotspot to hopespot: An opportunity for the Brazilian Atlantic Forest. Perspectives in Ecology and Conservation, 16(4), 208–214. doi: 10.1016/j.pecon.2018.10.002

Richardson, D. B., Kinlaw, A. C., MacLehose, R. F., & Cole, S. R. (2015). Standardized binomial models for risk or prevalence ratios and differences. International Journal of Epidemiology, 44(5), 1660–1672. doi: 10.1093/ije/dyv137

Roe, J. J., Ward Thompson, C., Aspinall, P. A., Brewer, M. J., Duff, E. I., Miller, D., … Clow, A. (2013). Green space and stress: Evidence from cortisol measures in deprived urban communities. International Journal of Environmental Research and Public Health, 10(9), 4086–4103. doi: 10.3390/ijerph10094086

Samuelsson, K., Giusti, M., Peterson, G. D., Legeby, A., Brandt, S. A., & Barthel, S. (2018). Impact of environment on people's everyday experiences in Stockholm. Landscape and Urban Planning, 171, 7–17. doi: 10.1016/j.landurbplan.2017.11.009

Sandifer, P. A., Sutton-Grier, A. E., & Ward, B. P. (2015, April 1). Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: Opportunities to enhance health and biodiversity conservation. Ecosystem Services, Vol. 12, pp. 1–15. Elsevier B.V. doi: 10.1016/j.ecoser.2014.12.007

São Paulo - Prefeitura Municipal de São Paulo. GeoSampa. 2020. Available in: <http://geosampa.prefeitura.sp.gov.br>. Last accessed in: 14th May 2021.

Shanahan, D. F., Bush, R., Gaston, K. J., Lin, B. B., Dean, J., Barber, E., & Fuller, R. A. (2016). Health Benefits from Nature Experiences Depend on Dose. Scientific

Reports, 6(1), 1–10. doi: 10.1038/srep28551

Shanahan, D. F., Fuller, R. A., Bush, R., Lin, B. B., & Gaston, K. J. (2015). The Health Benefits of Urban Nature: How Much Do We Need? BioScience, 65(5), 476–485. doi: 10.1093/biosci/biv032

Shi, Q., Chen, H., Liu, D., Zhang, H., Geng, T., & Zhang, H. (2020). Exploring the linkage between the supply and demand of cultural ecosystem services in Loess Plateau, China: a case study from Shigou Township. Environmental Science and Pollution Research, 27(11), 12514–12526. doi: 10.1007/s11356-020-07852-y

Soga, M., Cox, D. T. C., Yamaura, Y., Gaston, K. J., Kurisu, K., & Hanaki, K. (2017). Health benefits of urban allotment gardening: Improved physical and psychological well-being and social integration. International Journal of Environmental Research and Public Health, 14(1). doi: 10.3390/ijerph14010071

Soga, M., Yamaura, Y., Koike, S., & Gaston, K. J. (2014). Land sharing vs. land sparing: Does the compact city reconcile urban development and biodiversity conservation? Journal of Applied Ecology, 51(5), 1378–1386. doi: 10.1111/1365-2664.12280

Squillacioti, G., Bellisario, V., Levra, S., Piccioni, P., & Bono, R. (2020). Greenness availability and respiratory health in a population of urbanised children in North-Western Italy. International Journal of Environmental Research and Public Health, 17(1), 108. doi: 10.3390/ijerph17010108

Stott, I., Soga, M., Inger, R., & Gaston, K. J. (2015). Land sparing is crucial for urban ecosystem services. Frontiers in Ecology and the Environment, 13(7), 387–393. doi: 10.1890/140286

SUS, Sistema Unico de Saúde – Portal da Saúde DATASUS. Available in: <http://tabnet.datasus.gov.br/cgi/deftohtm.exe?sih/cnv/nisp.def> Last accessed in: 04th May 2021.

SVMA - Secretaria Municipal do Verde e do Meio Ambiente (2020). Mapeamento Digital da Cobertura Vegetal do Município de São Paulo. Relatório Final. Coord: Oliveira, V. P. São Paulo.

Tamosiunas, A., Grazuleviciene, R., Luksiene, D., Dedele, A., Reklaitiene, R., Baceviciene, M., … Nieuwenhuijsen, M. J. (2014). Accessibility and use of urban green spaces, and cardiovascular health: Findings from a Kaunas cohort study. Environmental Health: A Global Access Science Source, 13(1). doi: 10.1186/1476-069X-13-20

Tengberg, A., Fredholm, S., Eliasson, I., Knez, I., Saltzman, K., & Wetterberg, O. (2012). Cultural ecosystem services provided by landscapes: Assessment of heritage values and identity. Ecosystem Services, 2, 14–26. doi: 10.1016/j.ecoser.2012.07.006

Tischer, C., Gascon, M., Fernández-Somoano, A., Tardón, A., Materola, A. L., Ibarluzea, J., … Dadvand, P. (2017). Urban green and grey space in relation to respiratory health in children. European Respiratory Journal, 49(6). doi: 10.1183/13993003.02112-2015

van den Bosch, M., & Ode Sang. (2017). Urban natural environments as nature-based solutions for improved public health – A systematic review of reviews. Environmental Research, 158, 373–384. doi: 10.1016/j.envres.2017.05.040

Yeager, R. A., Smith, T. R., & Bhatnagar, A. (2020, May 1). Green environments and cardiovascular health. Trends in Cardiovascular Medicine, Vol. 30, pp. 241–246. Elsevier Inc. doi: 10.1016/j.tcm.2019.06.005

Discussão Geral e Conclusões

A distribuição do verde nas cidades varia de forma contínua entre formas extremas de *land sharing* e *land sparing*, muitas vezes não sendo possível enquadrar distintas regiões em uma ou outra categoria, especialmente em regiões sem planejamento urbano e com padrões de ocupação desordenado. Esse arranjo espacial provavelmente afeta a provisão de serviços ecossistêmicos, o que pode estar ligado, dentre outros fatores, a diferentes formas e capacidades de regular a ocorrência de doenças respiratórias e cardiovasculares.

Um padrão geral observado neste trabalho é que regiões mais *land sharing* tendem a ter menos internações por causas cardiovasculares, enquanto aquelas mais próximas de um *land sparing* parecem ter menos internações por causas respiratórias no sistema respiratório superior. Adicionalmente, há uma tendência de maiores densidades de florestas estarem associadas com a ocorrência de alergias, e áreas abertas, como vegetação campestre e áreas urbanas, terem um efeito na diminuição dessas enfermidades. Esses padrões observados demonstram a dificuldade no planejamento de paisagens visando a oferta de serviços ecossistêmicos, pois existem demandas conflitantes tanto em relação a quantidade quanto à distribuição do verde, no entanto para ambientes urbanos arranjos que propiciem maior contato com o verde se mostraram eficazes para prevenção de doenças. Nesse sentido é necessário pensar em paisagens multifuncionais dentro das cidades, diversificando os usos do solo e permitindo que sejam ofertados os serviços por todo território.

Em linhas gerais, o bem-estar humano parece estar associado ao contato direto com o verde, o que pode potencialmente ser amplificado por arranjos do verde que propiciem maiores áreas de contato entre vegetação e áreas construídas, como é o caso do *land sharing*. Paisagens com maior quantidade de verde entre as casas, sombreamento nas ruas, jardins e praças tendem tanto a estimular a prática de atividades ao ar livre quanto a coesão social das vizinhanças. Por outro lado, vegetação nativa densa e de alta qualidade pode oferecer outros tipos de serviços, como controle da qualidade do ar, manutenção da biodiversidade e até mesmo valores espirituais e estéticos. Entretanto, é necessário que esses locais tenham acesso público e seguro aos moradores, caso contrário provavelmente o fluxo de serviços pode ser diminuído.

Observando a distribuição das regiões *sharing* e *sparing* no município de São Paulo é possível notar que muitas vezes nenhuma dos dois padrões é claramente explícito, o que pode potencialmente configurar o pior cenário em termos de oferta de serviços. Muitas vizinhanças têm a total ausência de verde entre as casas, com uma alta densidade de moradias, mas também não possuem uma área verde concentrada e coesa, podendo não ter acesso nem aos serviços providos pelo *land sharing* e nem pelo *land sparing*. A maior parte desses distritos cinzas está nas periferias da cidade, onde além de menores taxas de renda também há baixas coberturas de verde. Outros trabalhos demonstraram que há uma forte associação entre renda e quantidade de verde na cidade de São Paulo, e isso se reflete nas taxas de internação por causas cardiovasculares e respiratórias. Outro ponto importante a ser levantado é que essas zonas periféricas muitas vezes têm grandes remanescentes de vegetação nativa próximos, contidos em unidades de conservação ou em terras privadas, mas que não possuem programas de uso e acesso público aos moradores, muitas vezes estando associados a insegurança.

A quantidade e a distribuição de verde se mostraram importantes para determinar as taxas de internação por saúde cardiovascular e respiratória, com diferentes respostas entre elas. Áreas verdes numa configuração mais voltada para *land sharing* parecem propiciar mais serviços ecossistêmicos que favorecem a saúde humana, principalmente no caso de doenças cardiovasculares e pulmonares. Sem dúvida, áreas verdes dispersas pela malha urbana prestam mais serviços do que desserviços, sendo assim componentes essenciais para o planejamento de paisagens urbanas mais saudáveis.

Resumo

A maior parte da população mundial vive em cidades, e estima-se que até 2050 sejam mais de 6,5 bilhões de pessoas habitando ambientes urbanos. O contato das pessoas com o verde tem se tornado cada vez mais escasso, o que pode levar ao aumento das taxas de adoecimento das populações urbanas. A importância do verde urbano na regulação da saúde dos moradores já é bem estabelecida, através dos chamados Serviços Ecossistêmicos. A dose de verde necessária para o bem-estar pode variar de acordo com diversos fatores ambientais e espaciais, mas estudos sobre o efeito da distribuição e do tipo de vegetação sobre a saúde ainda são incipientes. Investigamos como algumas doenças comuns do sistema respiratório e cardiovascular estão ligadas à cobertura e à distribuição do verde na maior megacidade do hemisfério sul, São Paulo, Brasil. A distribuição do verde pode ser acessada através do compartilhamento (*land sharing*) e da segregação (*land sparing*) de áreas verdes com áreas construídas. Desenvolvemos uma forma inovadora de mensurar de forma contínua os níveis de *land sharing* e *land sparing* para ambientes urbanos com base em índices de vegetação e associamos essas métricas às taxas de internação. Encontramos que para doenças cardiovasculares estratégias *land sharing*, onde a vegetação está difusa pela cidade, propiciando maior contato entre os moradores e o verde, têm a capacidade de diminuir as taxas de internação, assim como a presença do verde tem a capacidade de diminuir as taxas por problemas pulmonares. Para doenças no sistema respiratório superior, áreas abertas parecem ter um efeito de diminuição nas taxas de internação, enquanto áreas densamente vegetadas apresentaram um efeito de aumento nas internações por esta causa. Em linhas gerais os serviços ecossistêmicos prestados pelas áreas verdes parecem ser maiores que os desserviços, e áreas da cidade que propiciem maior contato com a natureza podem ter um papel na diminuição das hospitalizações.

Abstract

Most of the world's population lives in cities, and it is estimated that by 2050 there will be more than 6.5 billion people living in urban environments. With the increasing urbanization, people's contact with green spaces has become more scarce, which may be one of the causes for the increasing rates of illness in urban populations. The importance of urban green areas in regulating the health of residents is already well established, through the so-called ecosystem services. The dose of green required for well-being can vary according to various environmental and spatial factors, but studies on the effect of the distribution and type of vegetation on health are still incipient. Here we investigate how some common respiratory and cardiovascular diseases are linked to green cover and distribution in the largest megacity in the southern hemisphere, São Paulo, Brazil. The distribution of green can be accessed through the mixture (land sharing) and segregation (land sparing) of green areas with built areas. We develop a novel way to continuously measure the levels of land sharing and land sparing in urban environments based on vegetation indices and link these metrics to hospitalization rates. We found that for cardiovascular diseases, land sharing distribution, where vegetation is diffused throughout the city, has lower rates of hospitalization for cardiovascular and pulmonary diseases. Land sharing thus seems to provide more contact between residents and green areas, regulating the occurrence of these diseases. For superior respiratory diseases, open areas seem to have a decreasing effect on hospitalization rates, while densely vegetated areas have an increasing effect on hospitalizations for this cause. In general, the ecosystem services provided by green areas that affect human health seem to be greater than the disservices, and a more diffuse distribution of these areas throughout the city provides more contact with nature and thus may have a relevant role in reducing hospitalizations.

Referências Bibliográficas

Arantes, B. L., Castro, N. R., Gilio, L., Polizel, J. L., & Silva Filho, D. F. da. (2021). Urban forest and per capita income in the mega-city of Sao Paulo, Brazil: A spatial pattern analysis. Cities, 111. doi: 10.1016/j.cities.2020.103099

Araya, R., Montgomery, A., Rojas, G., Fritsch, R., Solis, J., Signorelli, A., & Lewis, G. (2007). Common mental disorders and the built environment in Santiago, Chile. British Journal of Psychiatry, 190(MAY), 394–401. doi: 10.1192/bjp.bp.106.024596

Astell-Burt, T., Mitchell, R., & Hartig, T. (2014). The association between green space and mental health varies across the lifecourse. a longitudinal study. Journal of Epidemiology and Community Health, 68(6), 578–583. doi: 10.1136/jech-2013-203767

Bertram, C., & Rehdanz, K. (2015). The role of urban green space for human well-being. Ecological Economics, 120, 139–152. doi: 10.1016/j.ecolecon.2015.10.013

Bush, J., & Doyon, A. (2019). Building urban resilience with nature-based solutions: How can urban planning contribute? Cities, 95, 102483. doi: 10.1016/j.cities.2019.102483

Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., … Walters, G. (2019, August 1). Core principles for successfully implementing and upscaling Nature-based Solutions. Environmental Science and Policy, Vol. 98, pp. 20–29. Elsevier Ltd. doi: 10.1016/j.envsci.2019.04.014

Dennis, M., & James, P. (2016). Site-specific factors in the production of local urban ecosystem services: A case study of community-managed green space. Ecosystem Services, 17, 208–216. doi: 10.1016/j.ecoser.2016.01.003

Dobbs, C., Hernández-Moreno, Á., Reyes-Paecke, S., & Miranda, M. D. (2018). Exploring temporal dynamics of urban ecosystem services in Latin America: The case of Bogota (Colombia) and Santiago (Chile). Ecological Indicators, 85, 1068–1080. doi: 10.1016/j.ecolind.2017.11.062

Fang, C. F., & Ling, D. L. (2005). Guidance for noise reduction provided by tree belts. Landscape and Urban Planning, 71(1), 29–34. doi: 10.1016/j.landurbplan.2004.01.005

Field, R. D., & Parrott, L. (2017, December 1). Multi-ecosystem services networks: A

new perspective for assessing landscape connectivity and resilience. Ecological Complexity, Vol. 32, pp. 31–41. Elsevier B.V. doi: 10.1016/j.ecocom.2017.08.004

Fischer, J., Abson, D. J., Butsic, V., Chappell, M. J., Ekroos, J., Hanspach, J., … von Wehrden, H. (2014, May 1). Land sparing versus land sharing: Moving forward. Conservation Letters, Vol. 7, pp. 149–157. Blackwell Publishing Ltd. doi: 10.1111/conl.12084

Gaston, K. J., & Soga, M. (2020). Extinction of experience: The need to be more specific. People and Nature, 2(3), 575–581. doi: 10.1002/pan3.10118

Grau, R., Kuemmerle, T., & Macchi, L. (2013, October 1). Beyond "land sparing versus land sharing": Environmental heterogeneity, globalization and the balance between agricultural production and nature conservation. Current Opinion in Environmental Sustainability, Vol. 5, pp. 477–483. Elsevier. doi: 10.1016/j.cosust.2013.06.001

Kellert, S. R., & Wilson, E. O. (1993). The Biophilia Hypothesis. Washington, DC: Island Press.

Lin, B. B., & Fuller, R. A. (2013). FORUM: Sharing or sparing? How should we grow the world's cities? Journal of Applied Ecology, 50(5), 1161–1168. doi: 10.1111/1365-2664.12118

MEA - Millennium Ecosystem Assessment (2005). Ecosystems and Human Well-being: Synthesis. Washington, DC: Island Press.

Metzger, J. P., Fidelman, P., Sattler, C., Schröter, B., Maron, M., Eigenbrod, F., … Rhodes, J. R. (2020). Connecting governance interventions to ecosystem services provision: A social-ecological network approach. People and Nature, 3(2), 266–280. doi: 10.1002/pan3.10172

Miller, J. R. (2005). Biodiversity conservation and the extinction of experience. Trends in Ecology and Evolution, 20(8), 430–434. doi: 10.1016/j.tree.2005.05.013

Ngom, R., Gosselin, P., Blais, C., & Rochette, L. (2016). Type and proximity of green spaces are important for preventing cardiovascular morbidity and diabetes—a cross-sectional study for Quebec, Canada. International Journal of Environmental Research and Public Health, 13(4). doi: 10.3390/ijerph13040423

Nowak, D. J., Crane, D. E., & Stevens, J. C. (2006). Air pollution removal by urban trees and shrubs in the United States. Urban Forestry and Urban Greening, 4(3–4), 115–123. doi: 10.1016/j.ufug.2006.01.007

Oliveira, S., Andrade, H., & Vaz, T. (2011). The cooling effect of green spaces as a contribution to the mitigation of urban heat: A case study in Lisbon. Building and

Environment, 46(11), 2186–2194. doi: 10.1016/j.buildenv.2011.04.034

ONU - United Nations, Department of Economic and Social Affairs (2017), Population Division. World Population Prospects: The 2017 Revision. V.1

ONU - United Nations, Department of Economic and Social Affairs (2018), Population Division. World Urbanization Prospects: The 2018 Revision

Roe, J. J., Ward Thompson, C., Aspinall, P. A., Brewer, M. J., Duff, E. I., Miller, D., … Clow, A. (2013). Green space and stress: Evidence from cortisol measures in deprived urban communities. International Journal of Environmental Research and Public Health, 10(9), 4086–4103. doi: 10.3390/ijerph10094086

Shanahan, D. F., Fuller, R. A., Bush, R., Lin, B. B., & Gaston, K. J. (2015). The Health Benefits of Urban Nature: How Much Do We Need? BioScience, 65(5), 476–485. doi: 10.1093/biosci/biv032

Soga, M., & Gaston, K. J. (2016, March 1). Extinction of experience: The loss of human-nature interactions. Frontiers in Ecology and the Environment, Vol. 14, pp. 94–101. Ecological Society of America. doi: 10.1002/fee.1225

Soga, M., Yamaura, Y., Aikoh, T., Shoji, Y., Kubo, T., & Gaston, K. J. (2015). Reducing the extinction of experience: Association between urban form and recreational use of public greenspace. Landscape and Urban Planning, 143, 69–75. doi: 10.1016/j.landurbplan.2015.06.003

Soga, M., Yamaura, Y., Koike, S., & Gaston, K. J. (2014). Land sharing vs. land sparing: Does the compact city reconcile urban development and biodiversity conservation? Journal of Applied Ecology, 51(5), 1378–1386. doi: 10.1111/1365-2664.12280

Solecki, W. D., Rosenzweig, C., Parshall, L., Pope, G., Clark, M., Cox, J., & Wiencke, M. (2005). Mitigation of the heat island effect in urban New Jersey. Environmental Hazards, 6(1), 39–49. doi: 10.1016/j.hazards.2004.12.002

Stott, I., Soga, M., Inger, R., & Gaston, K. J. (2015). Land sparing is crucial for urban ecosystem services. Frontiers in Ecology and the Environment, 13(7), 387–393. doi: 10.1890/140286

Theophilo, C. Y. S., Ribeiro, A. P., Moreira, E. G., Aranha, S., Bollmann, H. A., Santos, C. J., … Ferreira, M. L. (2021). Biomonitoring as a Nature-Based Solution to Assess Atmospheric Pollution and Impacts on Public Health. Bulletin of Environmental Contamination and Toxicology, 1–8. doi: 10.1007/s00128-021-03205-8

van den Berg, A. E., Maas, J., Verheij, R. A., & Groenewegen, P. P. (2010). Green space as a buffer between stressful life events and health. Social Science and Medicine, 70(8), 1203–1210. doi: 10.1016/j.socscimed.2010.01.002

van den Bosch, M., & Ode Sang. (2017). Urban natural environments as nature-based solutions for improved public health – A systematic review of reviews. Environmental Research, 158, 373–384. doi: 10.1016/j.envres.2017.05.040

Verbeek, P., and F.B.M. de Waal. 2002. The primate relationship with nature: Biophilia as a general pattern. In Children and nature, eds. P.H. Kahn, and S.R. Kellert, 1–28. Cambridge: MIT Press.

Wilson, E. O. (1984). Biophilia. Harvard University Press. Retrieved from https://www.degruyter.com/document/doi/10.4159/9780674045231/html

Anexos e Apêndices

SUPPLEMENTARY MATERIAL

1. Diseases selected (by International Code of Diseases - ICD)

Table S1 – Diseases classes considered for each of the three group of diseases that we considered in this study.

ICD	DISEASE NAME
	CARDIOVASCULAR SYSTEM
I10	Essential (primary) hypertension
I11	Hypertensive heart disease
I12	Hypertensive chronic kidney disease
I13	Hypertensive heart and chronic kidney disease
I21	Acute myocardial infarction
I22	Subsequent ST elevation (STEMI) and non-ST elevation (NSTEMI) myocardial infarction
	SUPERIOR RESPIRATORY SYSTEM
J01	Acute sinusitis
J03	Acute tonsillitis
J31	Chronic rhinitis, nasopharyngitis and pharyngitis
J32	Chronic sinusitis
	LOWER RESPIRATORY SYSTEM
J40	Bronchitis, not specified as acute or chronic
J41	Simple and mucopurulent chronic bronchitis
J42	Unspecified chronic bronchitis
J43	Emphysema
J45	Asthma

2. Correlation table of landscape variables

Table S2 – Poisson correlation table of landscape explanatory variables. The upper diagonal is the R^2 and lower diagonal the p-value. For statistical analysis we only used variables with less than 0.7 of correlation on the Generalized Linear Models (GLM).

	Street Tree Density	**Open Vegetation**	**Forest**	**Isolated Trees and Small Woods**	**Total Arboreal Cover**	**Total Green Cover**	**Sharing**	**Sparing Unevenness**	**Sparing Urban**	**Sparing Green**
Street Trees Density	-	-0.5246	-0.5357	0.5234	-0.274	-0.4002	0.4001	0.3456	0.1684	-0.5775
Open Vegetation	<0.00001	-	0.447	-0.0816	0.3904	0.6545	0.2509	-0.5463	-0.5922	0.5772
Forest	<0.00001	<0.00001	-	-0.1405	0.8925	0.8822	-0.0593	-0.4736	-0.6695	0.9532
Isolated Trees and Small Woods	<0.00001	0.42905	0.17219	-	0.3212	0.2365	0.8088	-0.263	-0.497	-0.0399
Total Arboreal Cover	0.00690	0.00008	<0.00001	0.00142	-	0.9516	0.3117	-0.5728	-0.8668	0.8936
Total Green Cover	0.00005	<0.00001	<0.00001	0.02035	<0.00001	-	0.3398	-0.6528	-0.9095	0.9265
Sharing	0.00005	0.01368	0.56625	<0.00001	0.00199	0.00071	-	-0.4175	-0.6697	0.025
Sparing Unevenness	0.00056	<0.00001	<0.00001	0.00963	<0.00001	<0.00001	0.00002	-	0.6775	-0.546
Sparing Urban	0.10092	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	-0.7591
Sparing Green	<0.00001	<0.00001	<0.00001	0.69962	<0.00001	<0.00001	0.80930	<0.00001	<0.00001	-

3. Green density histograms of each São Paulo City district

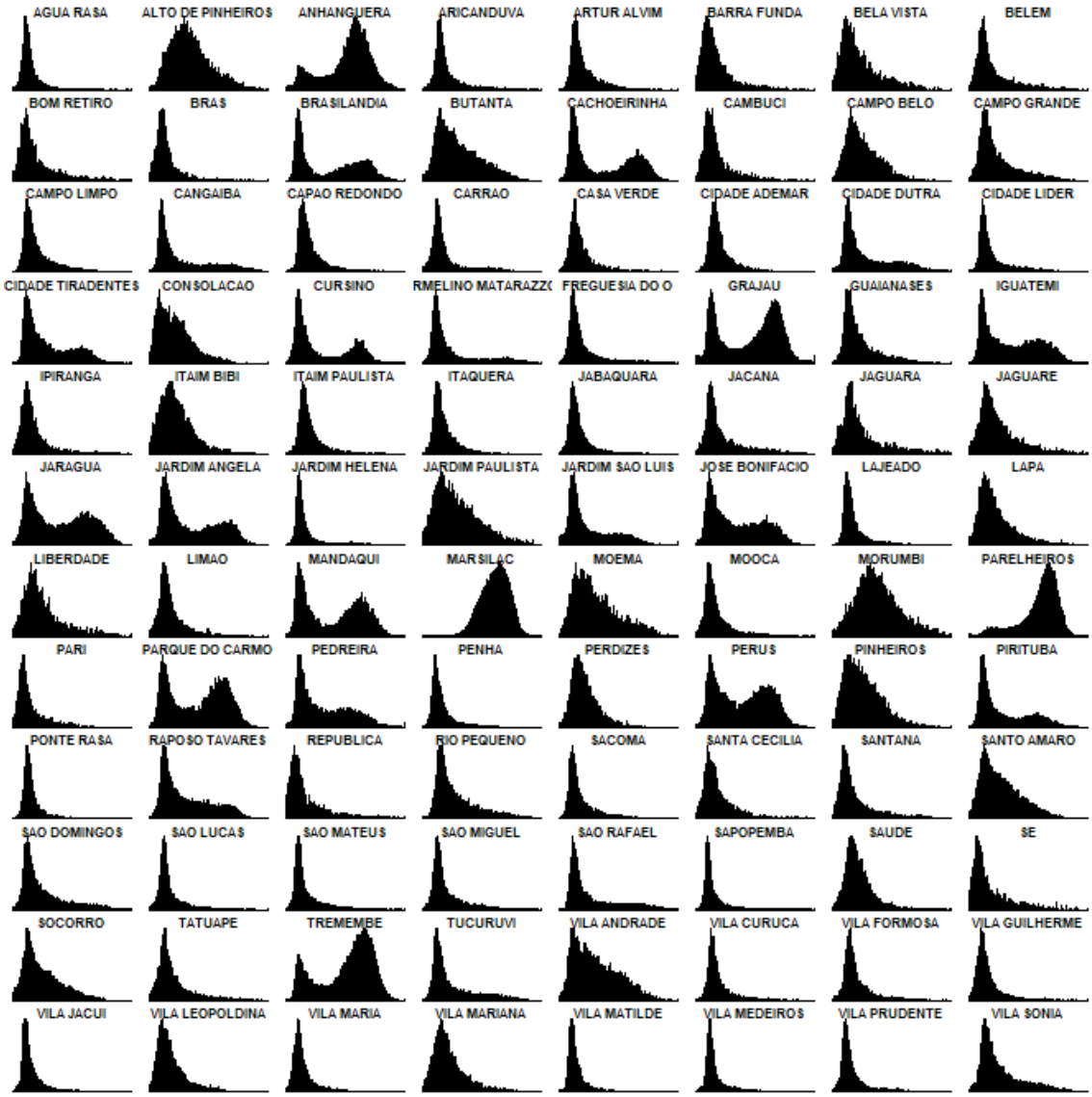

Figure S1 – Histograms of Enhanced Vegetation Index (EVI) values for the 96 districts of São Paulo city. One peak in the left being land sparing urban districts, one peak in the middle represents land sharing-like districts, one peak on right are land sparing forested districts, and two peaks are land sparing-like districts. The names of the districts appear above each histogram.

3. Graph of hospitalization rates distribution by season and year

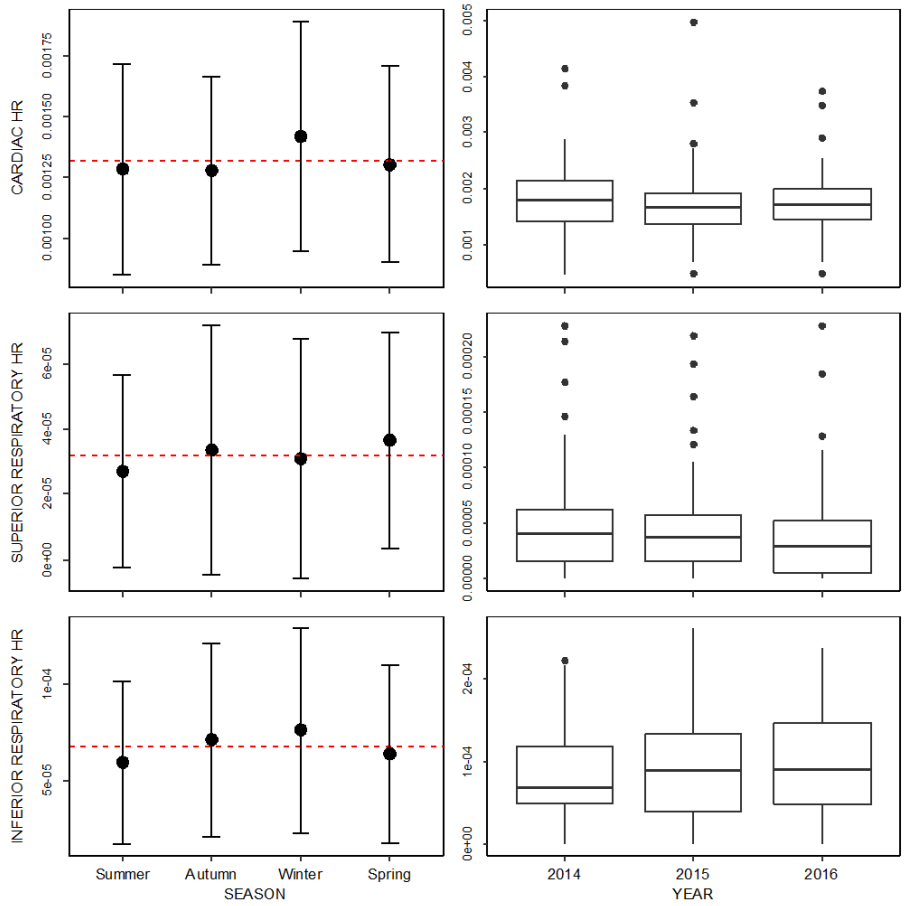

Figure S2 – Mean and standard deviations of Hospitalization Rates (HR) – number of hospitalizations per number of SUS users - for each group of diseases, each year and each station. The red dashed line in the left graphics represents the median considering the entire year for the three years. The points are the median for each season, considering the three years.

There is no effect of season or year according to an ANOVA analysis. Regardless, we tested the effects of landscape and vegetation parameters on hospitalization rates per year and per station using them in a binomial generalized linear model as factors. As results, there was no significant differences between hospitalization rates across the years, but we found significant difference according the season (Figure S2). For cardiac hospitalization rates the highest values were on winter (p-value < 0.001), while superior respiratory hospitalization rate was higher on spring, (p-value < 0.001), and for inferior respiratory hospitalization the highest values are in winter, (p-value < 0.001), showing the importance to consider the seasons in an additional analysis (see supplementary material 4).

4. Models selected by AIC, considering season.

Table S3 – Model selection results using AIC criteria, considering all SUS hospitalization in the city of São Paulo between 2014 and 2016 (all seasons) and the three diseases categories. The arrows in each line represents the position of the model in relation to the selection considering all stations, ↑ represents that the model rose from position on selection in relation to the reference; ↓ represents that the model has fallen on the model selection and ↗ represents that the model keep the position and increase the effect. AICc is the Akaike Information Criteria corrected; dAIC is the distance of AIC that the models are to the first; df are the degrees of freedom; weight represents the strength of model in relation to the others. Only the models with dAICc ≤ 2 are presented. The estimate is the value non-transformed (logit link binomial glm) of the size of effect for each variable.

	Model		AICc	dAICc	df	weight	Estimate	Std. Error	p-value
CARDIOVASCULAR	**ALL SEASONS**								
	Total Arboreal Cover + Sharing		**2377.5**	**0**	**4**	**0.9953**	**-0.30975** **-0.83377**	**0.0393** **0.05423**	**3.22E-15** **< 2E-16**
	SUMMER								
	Total Green Cover + Sharing	↑	1079	0	4	0.5895	-0.28991 -0.74046	0.11426 0.07049	3.91E-05 9.13E-11
	Total Arboreal Cover + Sharing	↓	1080.8	1.8	4	0.2412	-0.31139 -0.80291	0.08011 0.109772	0.000102 2.59E-13
	AUTUMN								
	Isolated Trees and Small Woods + Sparing Urban	↑	1086.8	0	4	0.8248	-1.1623 0.294678	0.318074 0.08239	0.000258 0.000348
	WINTER								
	Total Arboreal Cover + Sharing	↗	1092.6	0	4	0.6521	-0.21956 -0.85982	0.07512 0.10456	0.00347 < 2E-16
	SPRING								
	Total Arboreal Cover + Sharing	↗	1045.5	0	4	0.85	-0.38678 -0.94001	0.07873 0.10898	8.99E-07 < 2E-16
SUPERIOR RESPIRATORY	**ALL SEASONS**								
	Open Vegetation + Sparing Urban		580.5	0	4	0.2385	-2.46005 -0.67905	0.86407 0.23072	0.00441 0.00325
	Open Vegetation + Sparing Green		580.9	0.4	4	0.198	-1.88944 0.75036	0.77028 0.25677	0.01417 0.00347
	Open Vegetation + Forests		582.5	2	4	0.0873	-1.43535 0.67752	0.71185 0.25709	0.04376 0.00841
	SUMMER								
	Street Trees Density	↑	315.7	0	3	0.0991	-856.743	407.9818	0.0357
	Sparing Green	↑	316.3	0.7	3	0.0713	1.017	0.5041	0.0437
	AUTUMN								
	Null Model	↑	322.6	0	2	0.114	-	-	-

				WINTER					
	Open Vegetation + Sparing Urban	↗	336.1	0	4	0.1512	-3.6017 -1.5723	1.759 0.4666	0.040605 0.000753
				SPRING					
	Open Vegetation + Sparing Urban	↗	335.2	0	4	0.6966	-4.5549 -1.6573	1.6343 0.4221	0.00532 8.62E-05

INFERIOR RESPIRATORY				**ALL SEASONS**					
	Isolated Trees and Small Woods + Sparing Unevenness		**765.2**	**0**	**4**	**0.7117**	**-1.795** **-0.37**	**0.6562** **0.1665**	**0.00623** **0.02627**
				SUMMER					
	Total Arboreal Cover + Sharing	↑	401.8	0	4	0.0945	-0.6657 0.959	0.3649 0.4887	0.068129 0.049722
	Total Arboreal Cover + Sparing Unevenness	↑	402	0.2	4	0.0848	-1.1194 -0.4104	0.5063 0.2195	0.027 0.0615
				AUTUMN					
	Isolated Trees and Small Woods + Sparing Unevenness	↗	432	0	4	0.1527	-2.18569 -0.33161	1.03995 0.1568	0.0356 0.0344
				WINTER					
	Total Arboreal Cover + Sharing	↗	1045.5	0	4	0.85	-0.38678 -0.94001	0.07873 0.10898	8.99E-07 < 2E-16
				SPRING					
	Null Model	↑	423.8	0	2	0.0798	-	-	-

We check the effects of landscape and vegetation parameters by season, separately (Table S3). We ran all models per season and run a AIC model selection for each season. We can notice a pattern where the same best model selected for all seasons was selected in the season that we have the highest hospitalization rate (Figure S2) with a stronger effect. For example, in winter there is more hospitalizations by cardiovascular causes and on winter the best model has stronger effect than considering all seasons together.