A Spatial Analysis of Allergenicity Pressure from Street Trees in the City of Copenhagen

Table 0: *Distribution of work contribution of team members*

Team member	Student register no.	Work contribution
Emil Dietrich	617950	33%
Philip Liehr	566271	33%
Janis Klug	618316	33%

Abstract

Street trees in city scapes are attributed a broad range of beneficial effects to human well-being. This includes mitigation of hot daytime city temperature, reduced consumption of antidepressants for nearby residents, and serving as barriers in the dispersion of particulate matter. However, at the same time, street trees also release allergenic pollen into densely populated urban areas. With up to 20 % of the residents of the EU suffering from seasonal allergic rhinitis, street trees can aid in the advent of ocular symptoms, rhinorrhea, sneezing, and bronchial reactions. Climate change is broadly expected to exacerbate this problem. Taking the city of Copenhagen with little local research on allergenicity of trees as its study area, this paper examines the urban spatiality of allergenic potential of street trees. Following an identification of the present street tree genera composition and a development of a numeric allergenicity severity score on the genus level, we use the position of the street trees to estimate the spatial allergenicity pressure in the city of Copenhagen at a 5 x 5 m resolution. Our results indicate that the spatial distribution of allergenicity pressure is characterized by mild clustering with the highest allergenicity pressure estimated around northern Frederiksberg Municipality and the north of Copenhagen Municipality. The findings from this study can be expanded in future research by investing into comprehensive data processing and analyses and consideration of tree genus-specific pollen dispersal characteristics. In addition, interactions of tree pollen with environmental factors and the effects of non-street trees on the spatial distribution of pollen should be further investigated.

Introduction

Human health may benefit from the presence of street trees in several ways. For example, street trees can serve as a barrier against particulate matter in the urban atmosphere (Lehndorff et al., 2004; Freer-Smith et al., 2005). Planting trees may also serve as a measure to mitigate hot daytime temperatures in urban areas (Livesley et al., 2016; Helletsgruber et al., 2020). Moreover, urban residents living within 100 m of higher street tree density are less likely to be prescribed antidepressants (Marselle et al., 2020). But, street trees can also have adverse effects on human health via their pollen. Pollen causes the seasonal allergic rhinitis, commonly known as hay fever, which is an internationally classified disease according to ICD 10 j.30.1 (WHO, 2022). Up to 20 % of the residents of the European Union suffer from the seasonal allergic rhinitis (Zuberbier et al., 2014). It is for instance associated with ocular symptoms, rhinorrhea, sneezing, and bronchial reactions (Bousquet et al., 2001). Lastly, these symptoms are shown to decrease the psychological well-being of affected people (Aerts et al., 2020; Postolache et al., 2007; Stas et al., 2021).

The prevalence of the seasonal allergic rhinitis is expected to rise due to climate change (Shea et al., 2008; Ziello et al., 2012). In 2018 approx. 55 % of the world's population lived in urban settlements and this number is expected to reach 60 % by 2030 (UN 2018). Accordingly, a larger share of sensitized people will be exposed to pollen released by street trees in the coming decades. Although different studies on the pollen exposure in cities provide insights on the pollen spectra and seasonality (e. g. Fernández-Rodríguez, 2014; Nowak et al., 2012), there still remains a lack of research on the spatial distribution of pollen in cities (Werchan et al., 2017).

The city of Copenhagen - consisting of Copenhagen Municipality and Frederiksberg Municipality - is often considered a sustainable forerunner city that promotes the development of green infrastructure like street trees (Anderberg & Clark, 2013; EU, 2013; Floater et al., 2014). Previous studies have analyzed the diurnal patterns in pollen concentrations and its dispersion on different spatial scales in the city of Copenhagen for different plant genera (e. g. Alcázar et al., 2019; Skjøth et al., 2007 , 2008). Yet, an official information scheme on the allergenic effect of all street trees does not exist.

Against this background, our research aims to analyze the allergenic pressure caused by street trees in the city of Copenhagen. Our first objective is to identify the street tree genera of the city of Copenhagen and to develop a standardized allergenicity score for the street trees. Our second objective is the spatial analysis of the allergenic pressure caused by street trees in the city of Copenhagen.

Methods

An overview with all the methodological steps of this paper is provided at the end of this section (figure 3).

Study rea

The study area is the city of Copenhagen comprising both Copenhagen Municipality and Frederiksberg Municipality (figure 1). The city of Copenhagen has approximately 747.000 inhabitants and an area of 95.1 km² - thereof Copenhagen Municipality 643.000 inhabitants on 86.4 km² and Frederiksberg Municipality 104.000 inhabitants on 8.7 km² (Statbank Denmark, 2022). Copenhagen sprawls from its historical core to the west and south, consisting of multiple districts with differing characters. Frederiksberg is an affluent municipality, but its urban character is mostly indistinguishable from the surrounding Copenhagen Municipality districts.

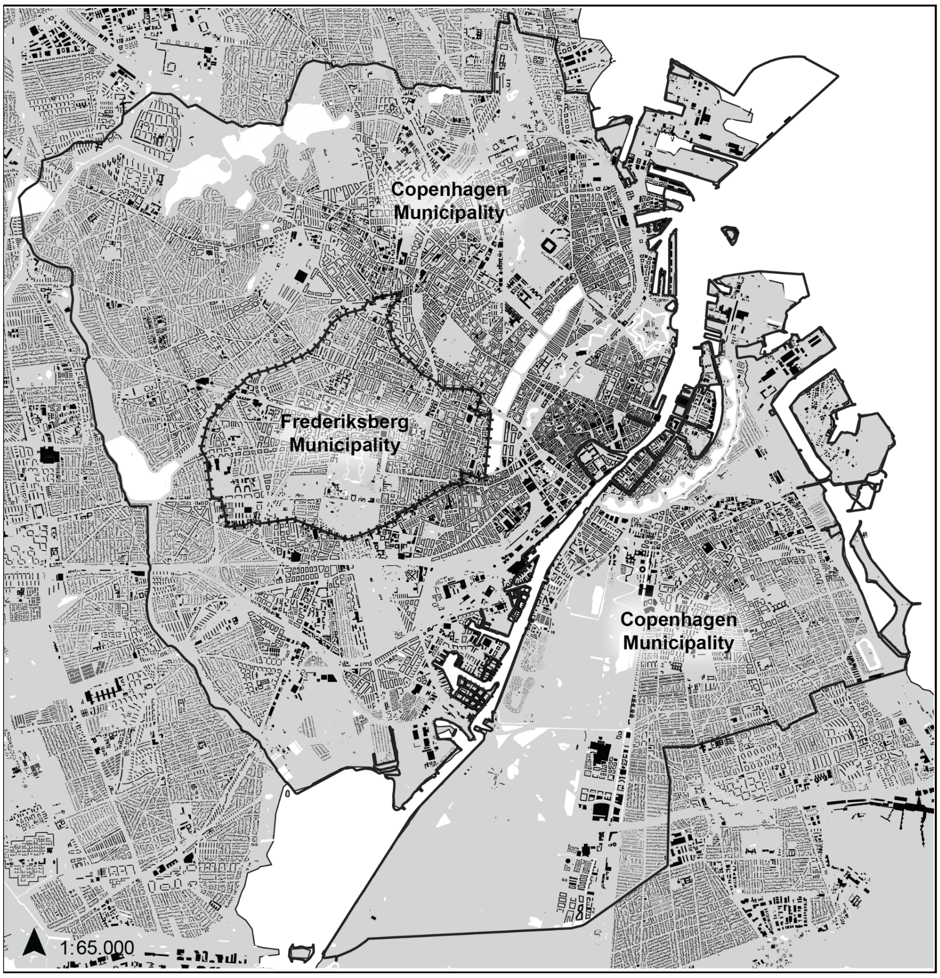

Figure 1: *The city of Copenhagen with its municipal borders*

Data

For Copenhagen Municipality, data on street trees was extracted from the publicly available dataset 'trae_basis K101' (Københavns Kommune, 2022). For Frederiksberg, data on street trees was provided directly to us by the municipality for the purpose of this study. Being part of different datasets created by separate entities, we bring awareness to the fact that the street tree data from Frederiksberg and Copenhagen Municipality might differ in quality and source methodology. We are not aware of, and do not account for any methodological differences in the creation of the street tree datasets. With the registration of street tree taxonomy varying in formatting and taxonomic rank, both between and within municipal datasets, we choose to standardize the registration on a genus level. The final dataset comprises 24.031 street trees across 43 different genera. 65 trees do not have an associated registration of genus and were therefore excluded from the analysis of this study.

The street tree data from Frederiksberg and Copenhagen Municipality was merged and cleaned with the Python programming language (Python Software Foundation, 2022). For the collaborative work on our Python scripts we applied the version control platform Github. Our software code can be downloaded from the respective repository: https://github.com/emilcarle/urban_sustainability_exam.

Allergenicity Score

As an initial analysis to determine the allergenetic effect caused by street tree pollen, we conducted a literature review with the search engines 'Google Scholar' and 'ResearchGate'. We searched for "pollen" e. g. in combination with the keywords "seasonal allergic rhinitis", "allergenicity", "tree", "cross allergies", "exposure", "distribution", and "flight distance". As a core study, we picked the review from D'Amato et al. (2014) on 'Allergenic pollen and pollen allergy in Europe' published in the European Journal of Allergy and Clinical Immunology with more than 1.300 citations. Additionally, we browsed websites from various healthcare industry companies - for instance IMS Health Incorporated (2022) - to derive information on the allergenicity of tree genera. Based on the literature review, we assigned the street tree genera in the city of Copenhagen to five allergenicity levels and a corresponding numerical score from 0 to 5 (table 1).

Table 1: *Allergenicity levels with corresponding allergenicity scores*

Allergenicity level	Allergenicity score
no allergies reported	0
low	1
mild	2
moderate	3
high	4
very high	5

Spatial Allergenicity Pressure

To estimate the allergenic pressure (the quantity of nearby allergenic trees and their allergenic potential at a given point in space) in all areas of the city of Copenhagen, we employed buffers. Following the standardization of genera in the dataset, a 500 m buffer was generated from every tree point as multipolygons on a genus level. We selected a buffer radius of 500 m, in which we expected an increased pollen concentration (e. g. Adams-Groom et al., 2017; Bacles and Ennos, 2008; Bricchi et al., 2000; Werchan et al., 2017). The allergenetic pressure was kept constant within the radius without a decay with respect to source distance. The radius corresponds to the micro till local-scale for the variability of atmospheric constituents following Seinfeld & Pandis (2006).

The vector buffers were rasterized and summed up to generate the final allergenicity pressure map (visualized in figure 2), using the geographic system application QGIS (QGIS, 2022). We chose to base the rasterization on a 5 x 5 m grid of Copenhagen and Frederiksberg Municipalities to allow for standardized summing of all 43 genus rasters. As a consequence of calculating the tree buffers as multipolygons on the genus level without internal overlap, the final allergenicity pressure index does not account for the density of trees with the same genus.

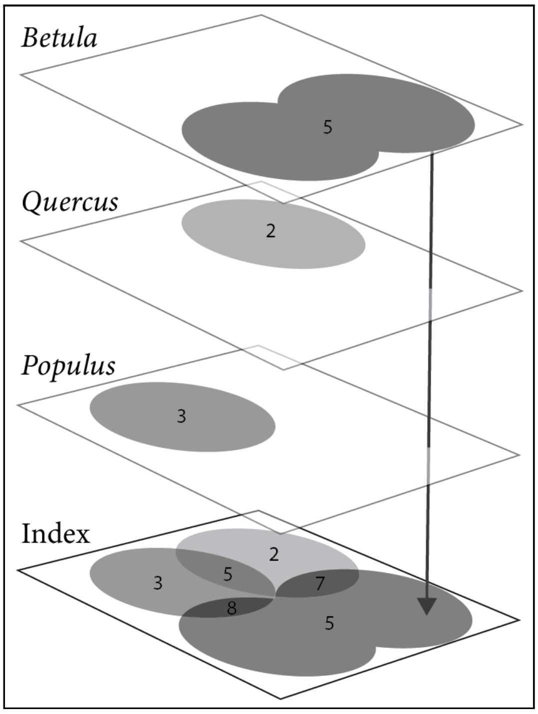

Figure 2: *Schematic visualization of the additive buffer method applied in the creation of the allergenicity pressure map for the city of Copenhagen. This representation is purely conceptual and does not include actual tree buffers or the full list of genera included in the study.*

Analysis of Spatial Autocorrelation

To analyze the global spatial autocorrelation of values for the allergenicity score, we calculated the Moran's I index following Moran (1950) with the spatial analysis software GeoDa (Anselin et al., 2006). For that, the raster map on the allergenic pressure was vectorized as input for the analysis. Due to computational limits, adjacent cells with the same allergenicity pressure were merged into larger polygons instead of conducting a cell-wise vectorization. For the spatial weights, we selected a neighborhood setting based on Queen contiguity. To account for the fact that nearby allergenicity pressure polygons are originally affected by the same 500 m tree buffers (and as thus are inherently spatially correlated), we employed a higher order contiguity of five without including lower order neighbors. For the calculation of the Moran's I index, five polygons had to be ignored, as they were isolated from neighbors.

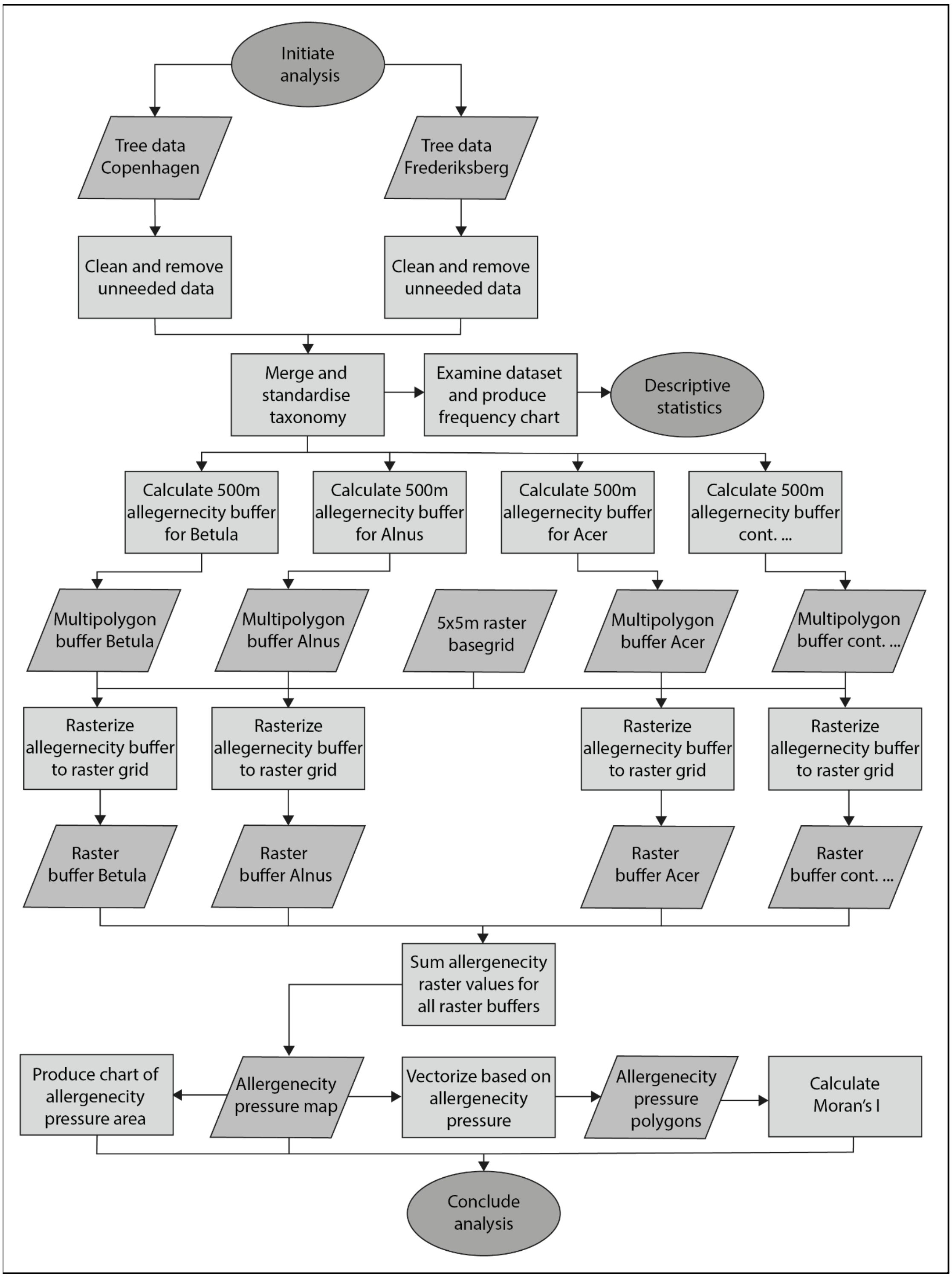

Figure 3: *Flowchart of all processes and methods conducted in this study.*

Results

Figure 4 shows the number of street trees in Copenhagen by genera. Genera with less than 100 planted individuals are not visualized in figure 4. With approximately 7.500 individuals, *Tilia sp.* has the highest frequency among the street trees in the city of Copenhagen. The second most planted street tree with about 3.000 individuals is the *Platanus sp.*, followed by *Sorbus sp.* and *Acer sp.* with approx. 2.000 individuals each.

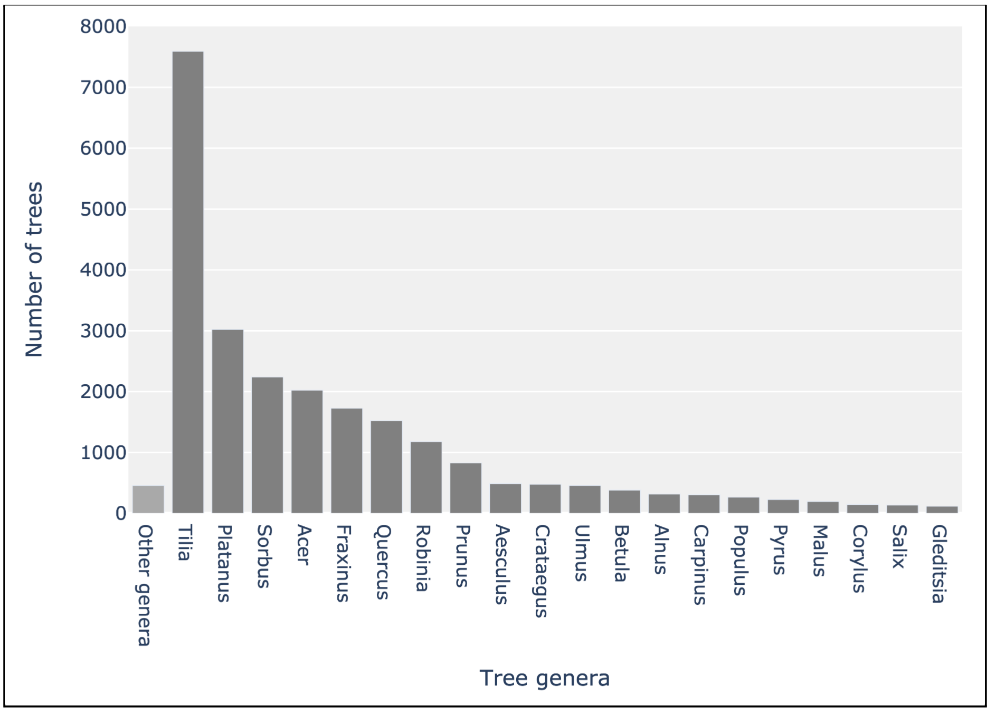

Figure 4: *Number of street trees by genera in the city of Copenhagen*

Primarily due to the dominant presence of *Tilia sp., Platunus sp.*, *Sorbus sp.*, and *Acer sp.*, all with an allergenicity score of 1, the majority of street trees in the city of Copenhagen fall within this allergenicity score (see table 2). Trees with more severe allergenicity scores of 3, 4, and 5 combined comprise only 4.6 % of the street trees in the city of Copenhagen.

Table 2: *Number of street trees in the city of Copenhagen by allergenicity score*

Allergenicity score	Number of trees	% of trees
0	667	2.8%
1	18516	77.1%
2	3733	15.5%
3	266	1.1%
4	467	1.9%
5	382	1.6%

The estimated spatial distribution of allergenicity pressure is shown in figure 5. The allergenicity pressure index itself ranges from 1 (very low allergenicity pressure) to 42 (highest estimated allergenicity pressure). The maximum value of the index range is a consequence of the methodology of the index' creation and would be different in other study areas with different compositions and placements of tree genera. Allergenicity pressure appears to be mildly clustered around certain key areas with high concentrations of allergenic trees. This includes outer Østerbro (northern Copenhagen Municipality) and northern Frederiksberg. There is no decisive observable difference between Frederiksberg Municipality and comparably densely populated areas of Copenhagen Municipality. Unsurprisingly, there is little estimated allergenicity pressure in areas with low street density where the density of street trees is (consequently) also low. These areas, like Amager Fælled and Kalvebod Fælled covering the southern part of Copenhagen Municipality, contain large quantities of trees that are not included in this analysis, solely accounting for trees placed on streets.

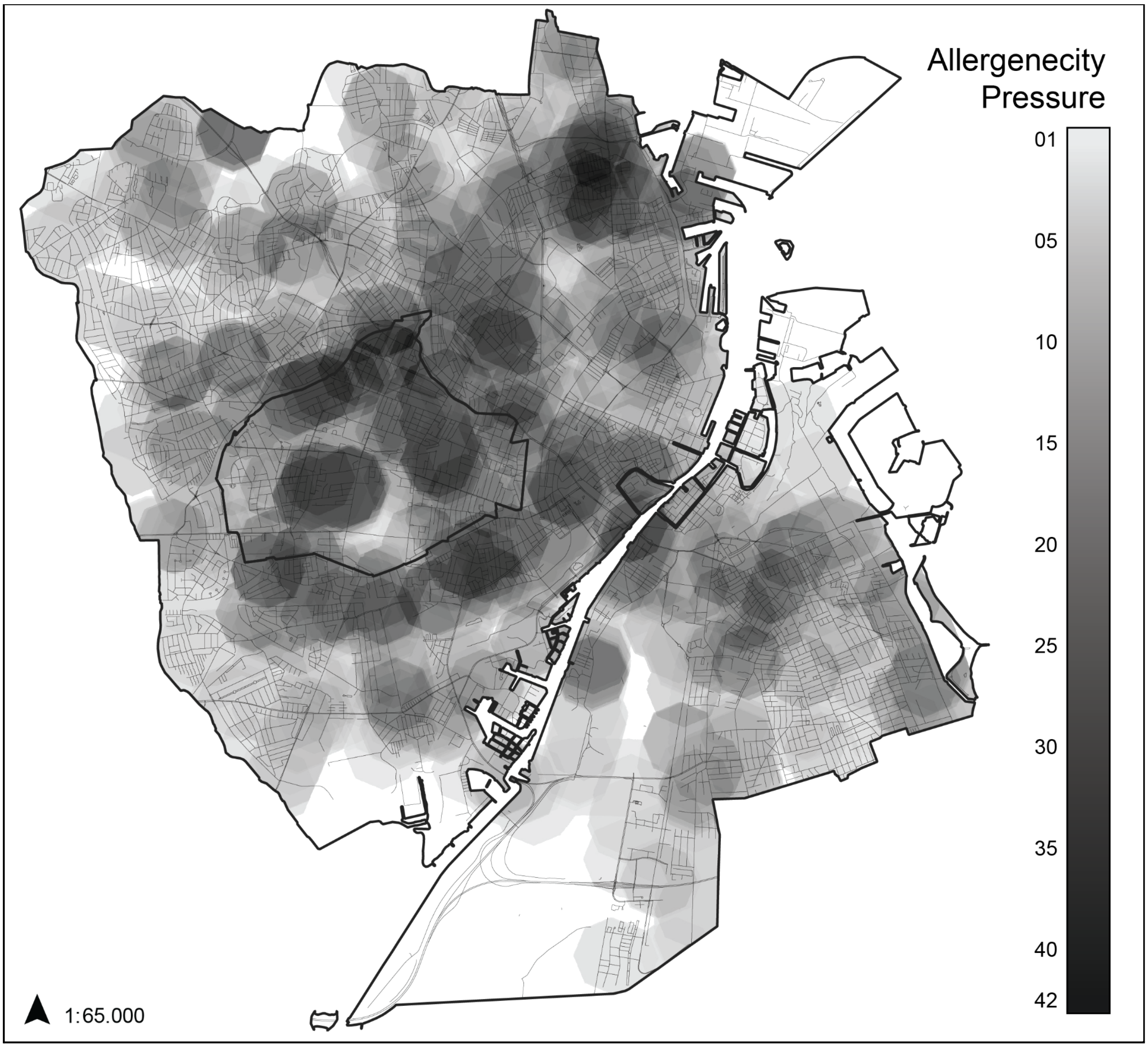

Figure 5: *Spatial distribution of allergenicity pressure in the city of Copenhagen.*

Overall, the areal distribution of allergenicity pressure in the city of Copenhagen is fairly equal across index values with an average coverage around 3.5 km² (see figure 6). However, for index values exceeding 25, there is a clear drop-off in coverage with index values more than 35 covering less than 0.5 km².

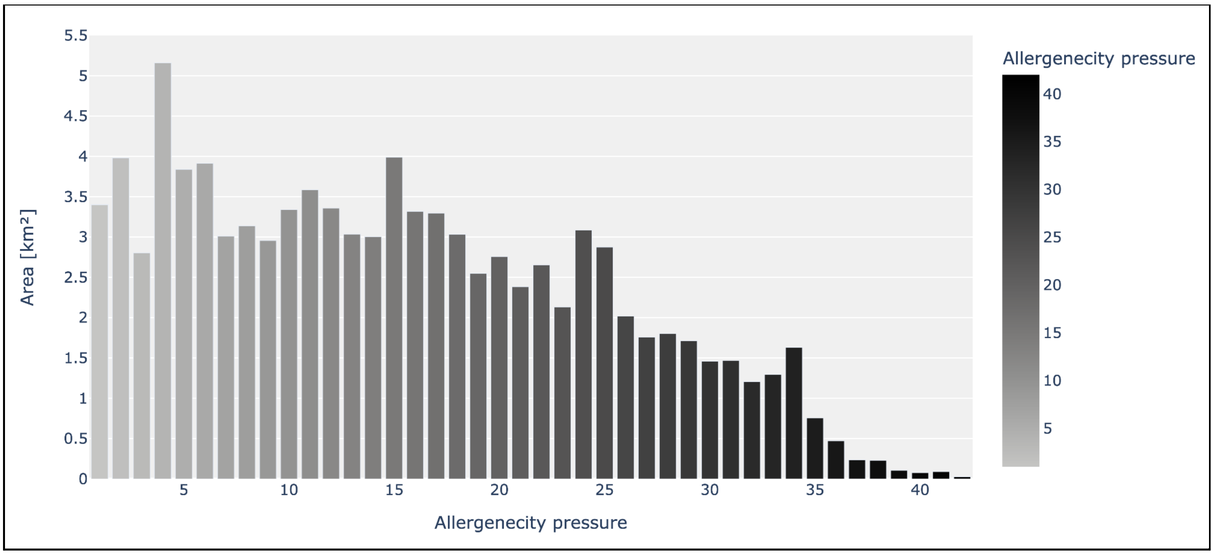

Figure 6: *Area coverage of allergenicity pressure index values in the city of Copenhagen.*

The calculated Moran's I index for the allergenicity pressure in the city of Copenhagen indicates a positive autocorrelation with a Moran's I of 0.58 (O'Sullivan & Unwin, 2010). Based on 99 permutations with a pseudo p-value of 0.01, the null hypothesis was rejected that there is no spatial autocorrelation in the data. The density of points on the Moran's I scatter plot is overall high without clear patterns of dispersion (figure 7). The scatter plot furthermore shows a dominating role of high-high, followed by low-low clustering.

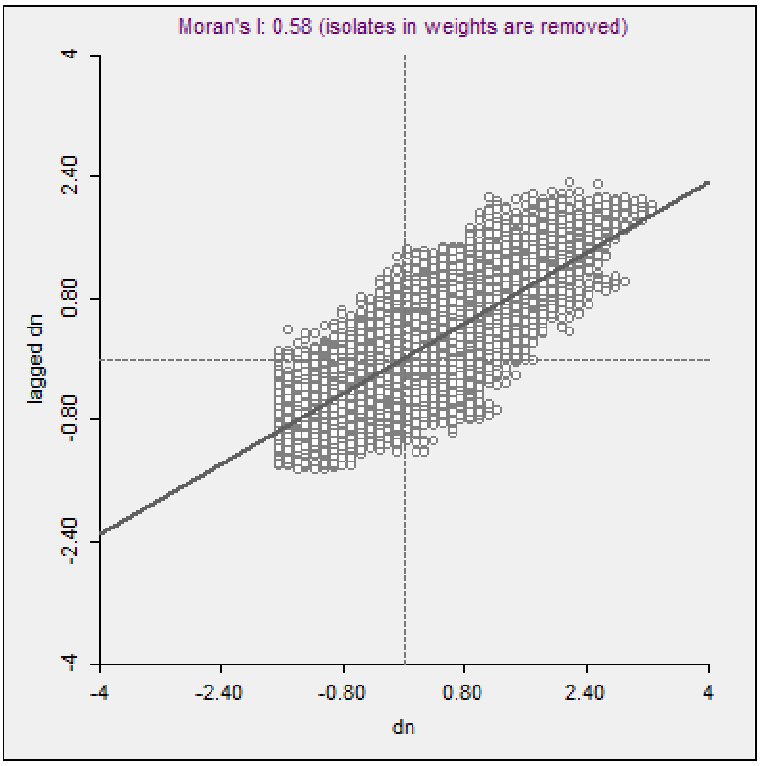

Figure 7: *Moran's I for estimated allergenicity pressure in the city of Copenhagen.*

Discussion

In Copenhagen Municipality, 4.6 % of the planted street trees have a moderate to very high allergenicity. A very high allergenicity pressure can be observed on less than 0.5 % of the area of the city of Copenhagen. In the city of Copenhagen, the allergenicity pressure by street tree pollen is highest in and around Frederiksberg Municipality as well as the northern part of Copenhagen Municipality. This somewhat clustered distribution is confirmed by the Moran's I of 0.58 (pseudo p-value = 0.01).

Actual local patterns of pollen distribution are furthermore expected to appear much more heterogeneous, because of their many interactions with the environment and tree genus-specific characteristics. The atmospheric transport and the aerial concentration of tree pollen is influenced by various meteorological factors - such as wind speed, wind direction, air temperature, and relative air humidity (Bartková-Ščevková, 2003; Maya-Manzano et al., 2017; Werchan et al., 2017). In addition, pollen dispersal abilities can differ between tree genera, depending on pollen size, form, and density (Bricchi et al., 2000; Seinfeld & Pandis, 2006; Skjøth et al., 2009). The pollen production differs between genera with tree height and width also playing a role in pollen dispersal (Adams Groom et al., 2017; Sugita et al., 2010).

Another factor affecting the allergenicity pressure of tree pollen is the atmospheric composition. Particulate matter (PM) or exhaust gasses like NO_2 and SO_2 may lead to stronger allergic reactions in sensitized people (Cahill, 2018; Cakmak et al., 2011; D'Amato et al., 2014; Sousa et al., 2012). The city of Copenhagen features relatively clean air (EU, 2013). But, interactions between tree pollen and atmospheric pollutants could occur e. g. in the vicinity of the port areas - like the cruise terminal 'Langelinie' - or along streets with high traffic volumes. In addition to the effects of atmospheric pollutants, cross-effects between pollen from different tree and plant genera might also lead to more severe and common allergic reactions (D'Amato et al., 2007). However, at which exposure level interactions between tree pollen and atmospheric pollutants or cross-effects trigger a more severe allergic reaction could not be attained during the literature review for this study. The allergic response threshold to exposure of a certain tree genus pollen is still undergoing research (Steckling-Muschack et al., 2021). Yet, the findings from this study can serve as a baseline for future analyses from which additional environmental and genus-specific factors can be studied further.

For every street tree genus, we assumed that a buffer radius of 500 m from each tree center describes allergic relevant pollen dispersal. This represents a simplification of the expected pollen dispersal that, among other factors, does not consider a gradient in pollen quantity with source distance or the highly relevant effects of wind. Furthermore, this radius was based on a literature review on the topic of spatial pollen distribution, where studies still follow inconsistent methodologies (Werchan et al., 2017). This includes varying heights for pollen traps and differing approaches to account for environmental disturbances (e. g. Maya-Manzano et al., 2017; Rojo et al., 2020; Velasco-Jiménez et al., 2013). Developing genus-specific buffer radii with gradients in pollen concentration could serve as a meaningful direction for further research.

The strong positive autocorrelation in the allergenicity score values, indicated by the Moran's I of 0.58 (pseudo p-value = 0.01), has to be interpreted with caution. This result may have occurred due to the higher order contiguity setting in the creation of the spatial weights. With a higher order of five, polygons in areas of dense assemblages of small polygons might still have been inside the buffer radii of single trees. This would increase the measured positive autocorrelation. With higher computing power, a pixel-based vector layer could have been used for the calculation of the Moran's I index allowing more standardized higher order contiguity settings. Despite the computational limitation of our study, the clustered distribution is observable in figure 5 and obviously goes back to the historical development of the city of Copenhagen.

So far, our study appears as a promising starting point to analyze the allergenic pressure caused by street trees in the city of Copenhagen. Implementing meteorological and other environmental factors, as well as considering genus-specific pollen dispersal could further improve the informative value of the gained results. Such findings could then be used by urban planners to make the multiple benefits of urban green infrastructure accessible to a wider range of citizens in the city of Copenhagen.

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