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# Association between local airborne tree pollen composition and surrounding land cover across different spatial scales in Northern Belgium

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ABSTRACT

Airborne pollen are important aeroallergens affecting human health. Local airborne pollen compositions can pose health-risks for the sensitized population, but at present little is known about fine-scale pollen composition patterns.

The overall objective of this study is to determine local variations in tree pollen composition with passive samplers and to identify the surrounding landscape characteristics that drive them. In February–May 2017, during the tree pollen season, airborne tree pollen were measured by passive sampling at 2 m height above ground-level in 14 sites in the Flanders and Brussels-Capital region (Belgium). Non-metric multidimensional scaling was used to investigate environmental gradients that determine the pollen composition and amounts. Land cover types were identified across spatial scales ranging between 20 m and 5 km.

The passive samplers detected the same pollen taxa during the same time windows as the validated volumetric Burkard samplers. Using passive samplers, we were able to measure local airborne pollen compositions. *Corylus* and *Platanus* pollen were associated to urban areas; *Populus, Juglans* and *Fraxinus* pollen to agricultural areas; forests and wetlands were sources of *Alnus* and *Quercus* pollen. *Salix, Populus* and *Betula* pollen were also mainly associated to wetlands. The landscape context drives the airborne tree pollen composition at a meso-scale (1−5 km) rather than at finer scale (20−500 m). Thus, land cover types (e.g. forest, bush land, agricultural lands and wetlands) surrounding urban areas may increase exposure to allergenic pollen in the urban area, potentially affecting the health of a large proportion of the population.

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## 1. Introduction

Nature and urban green spaces provide ecosystem services associated with numerous health benefits (Twohig-Bennett and Jones, 2018). In urban areas, people have a reduced exposure to nature (Cox et al., 2018) and experience increased symptoms of asthma and allergies (von Hertzen and Haahtela, 2006). Therefore, urban green spaces are of utmost importance for improving physical (Braubach et al., 2017) and mental health (Barton and Rogerson, 2017; Bratman et al., 2019). However, nature and green spaces can also be a source of aeroallergens, especially when allergenic pollen producing tree species are present (Pecero-Casimiro et al., 2019).

Airborne pollen from many wind-pollinated plant species have allergenic potential. Worldwide allergenic pollen exacerbate allergies in up to 25 % of the population (Passali et al., 2018). It is estimated that 100 million Europeans suffer from allergic rhinitis, yet 45 % of this group remains undiagnosed (The European Academy of Allergy and Clinical Immunology (EAACI), 2016). Several factors such as meteorological conditions (e.g. wind speed and direction, humidity and precipitation) (Borycka and Kasprzyk, 2018), presence and type of landscape elements and infrastructure may influence the pollen dispersal and persistence in the atmosphere (Rojo et al., 2015). Long term measurements in Brussels, the capital city of Belgium, show increasing trends in pollen concentrations associated with increasing temperature and radiation and inverse associations with relative humidity and rainfall (Bruffaerts et al., 2018).

In European aerobiological networks, airborne pollen concentrations are monitored by the Hirst method at building roof-level, i.e. 10–20 meters above ground (Galán et al., 2014), optimal for homogeneous measurements representative for an approximate 25 km radius area (Oteros et al., 2019; Rojo et al., 2019). Depending on the local landscape, topography and climate, the measured pollen composition can even be relevant for a 50 km radius area (Gehrig, 2019). Pollen can be transported over long distances, contributing to an extension of the pollen season (Bogawski et al., 2019a). Short-distance transport, however, contributes to the most important pollen peaks (Rojo and Pérez-Badia, 2015). Nevertheless, standardized measurements are not taken at ground level, and as such outside the regular human breathing zone, potential local variations in pollen composition at lower height are poorly taken into account (Hjort et al., 2016; Rojo et al., 2019; Werchan et al., 2017). Peel et al. (2013) have shown that the actual pollen-dose can differ strongly from the measured regional pollen concentration.

State of the art birch pollen dispersion models still have difficulty taking into account fine-scale patterns of birch habitation (Kurganskiy et al., 2020). Local tree composition is expected to have an effect on the local pollen exposure (Weinberger et al., 2016) and to be a risk factor for tree pollen allergic sensitization (Lovasi et al., 2013). A better understanding of the drivers of local pollen composition could lead to improved urban green management and better health outcomes (Weinberger et al., 2016). While in palynology the link between regional vegetation and pollen has been widely studied (Fletcher and Thomas, 2007), we aim to contribute to the understanding of current health risks of poorly measured and modeled local pollen compositions.

The overall objective of this study is to measure local variations in airborne tree pollen composition by passive sampling at 2 m height above ground-level. We study how the passive measurements correspond to standardized sampling measurements regarding airborne pollen composition as well as timing of detection during the season. Then we want to identify the environmental factors of the surrounding landscape that drive the local airborne pollen composition. In addition, we test multiple spatial scales to find at which spatial scales the environment affects the local airborne tree pollen composition the most and are thus of relevance for exposure studies.

## 2. Materials and methods

### 2.1. Study area

The study was conducted in Flanders, the northernmost of the three administrative regions of Belgium, as well as in the Brussels-Capital Region, which is geographically enclosed within the Flanders region. Flanders has an area of 13,522 $km^2$ and a population density of 482 inhabitants per $km^2$. The Brussels-Capital Region has an area of 162 $km^2$ and a population density of 7442 inhabitants per $km^2$. The climate according to Köppen is a maritime temperate climate (Cfb) (Peel et al., 2007).

### 2.2. Airborne pollen sampling

#### 2.2.1. Passive samplers

The design of the passive samplers that were used in this study was inspired by the Durham pollen trap for gravitational sampling (Durham, 1946). Such Durham-type passive samplers have already been used by Katz and Carey (2014) to measure local pollen amounts. Passive sampling of airborne pollen relies on gravity and intake flow is not controlled. Two parallel panels spaced 30 cm apart were mounted at 2 m height above the ground (Fig. 1a). On the bottom panel a glass slide with a tape covered with an adhesive (Vaseline) was placed, similar to the construction of the drum in the Hirst volumetric spore trap. The sticky surface of 10 mm x 45 mm was capable of trapping airborne pollen (Fig. 1b). The top plane served to protect the glass from rain and potential debris. The trap was encapsulated by a medium-sized mesh to exclude birds. After two weeks of exposure, samples were collected to avoid oversaturation of particles on the capture surface, and replaced by unexposed glass slides. The exposed samples were then sealed on microscopy glass slides (Fig. 1c) with mounting medium (500 mL glycerol, 50 g gelatin, 5 g phenol diluted in 500 mL distilled water) according to Galán et al. (2014).

#### 2.2.2. Sampling sites

Passive sampling was performed during the main tree pollen season of 2017, starting from February 2$^{nd}$ until May 25$^{th}$. One pollen season generally suffices to obtain insights in the drivers of pollen composition

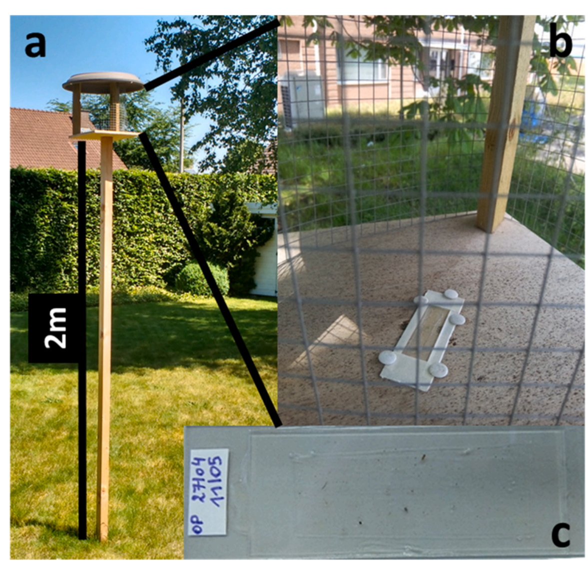



**Fig. 1.** (a) Durham-type passive pollen sampling construction, mounted at 2 m height above ground level. (b) Sticky tapes were placed in the sampler for successive periods of two weeks per tape (c) The samples were mounted on glass slides and labeled before proceeding to pollen identification and counting by light microscopy.

as shown in previous studies (Hugg et al., 2017; Weinberger et al., 2016; Werchan et al., 2017). During this period 8 glass slides with a sticky surface were consecutively exposed at 14 sampling sites. Passive pollen samplers were placed on 14 sites in Flanders and the Brussels-Capital Region (Fig. 2) to monitor the local abundance of pollen of 12 wind pollinated tree taxa: horse chestnut (*Aesculus hippocastanum*), walnut (*Juglans* spp.), beech (*Fagus sylvatica),* oak (*Quercus* spp.), alder (*Alnus* spp*.)*, hazel (*Corylus avellana*), hornbeam (*Carpinus betulus*), birch (*Betula* spp.), poplar (*Populus* spp*.),* willow (*Salix* spp.), ash (*Fraxinus excelsior*) and plane (*Platanus* spp.). The authors selected these taxa in consultation with the Belgian Aerobiological Surveillance Network. Not all the taxa listed are strictly wind-pollinated, pollen from *Salix* and *Aesculus hippocastanum* can also be transported by insects.

Two of the fourteen passive pollen samplers were placed close to the reference stations in Brussels (10 m) and Genk (300 m). The reference stations are part of the Belgian Aerobiological Surveillance Network (Sciensano, www.airallergy.be) and monitor average daily pollen concentrations (grains/m$^3$) on building rooftops at about 15 m above ground level, with Hirst-type 7-day volumetric spore traps (Burkard Manufacturing co., U.K.). Three passive samplers were placed within a 30 km buffer around each of the two reference stations (namely in Mechelen, Kessel Lo, Roosdaal, Heusden-Zolder, Hasselt and Sint-Truiden), and six other samplers were placed outside each of the two 30 km buffers (namely in Gent, Hoboken, Bornem, Aarschot, Oplinter and Neerpelt) (Fig. 2). No data were collected in the most Western province of the region because of the coastal climate and divergent landscape.

#### 2.2.3. Pollen identification

Given the taxa selected in this study, pollen grains were identified by light microscopy (using the Leica optical microscopes with a total magnification of 400 ×; 10 × ocular lens and 40 × objective lens). Two longitudinal swipes were read and counted, each swipe with a length of 45 mm and a width of 0.5 mm, corresponding to an area of 45 mm$^2$ (10 % of the total sample surface (10 × 45 mm); standard protocol) (Galán et al., 2014). The pollen concentrations obtained through passive sampling should be interpreted as deposition rates: the number of grains that is deposited on a given surface during a certain time, expressed in pollen/cm$^2$. The volumetric samplers measure actual pollen concentrations: number of grains present in a given volume of air sampled during a certain time, expressed as pollen/m$^3$. We assumed that higher pollen concentrations lead to higher deposition rates and that therefore the two methods yield pollen data that are correlated. The passive sampling results cover a 14 day period resulting in a biweekly concentration. By dividing the deposition rate by 14, we obtain an average daily deposition rate for each exposure period. For the volumetric samplers at the reference stations daily pollen concentration values were available. These daily values were averaged for the same 14 day exposure periods. The average daily values obtained by the passive and the volumetric samplers were visually compared. Previous studies have shown that passive samplers and volumetric samplers show similar temporal variation and peak periods (Piotrowska and Weryszko-Chmielewska, 2003; Teranishi et al., 2006).

### 2.3. Pollen composition

To characterize the local airborne pollen composition at each site, the total pollen count (per taxa) from passive sampling was divided by the number of sampling days and multiplied by 30 to obtain estimates of monthly pollen loads. The monthly average pollen taxa data were then log-transformed.

Ordination of the sampling sites based on pollen taxa composition was obtained by non-metric multidimensional scaling (NMDS). An initial exploratory run, testing one- to four-dimensional ordination, showed that a two-dimensional ordination resulted in an acceptable stress score of $< 0.1$ (Kenkel and Orloci, 1986). NMDS presents the sampling sites in two-dimensional space and based on Bray-Curtis distances a stress level is determined. The stress level quantifies the compositional dissimilarity between the original and current position of the sampling sites. The iterative process (set to a maximum of 100 iterations) aims to minimize the stress value (Clarke, 1993). Ordination was performed using the *vegan* package (Oksanen et al., 2019) for R software (Core Team R, 2017).

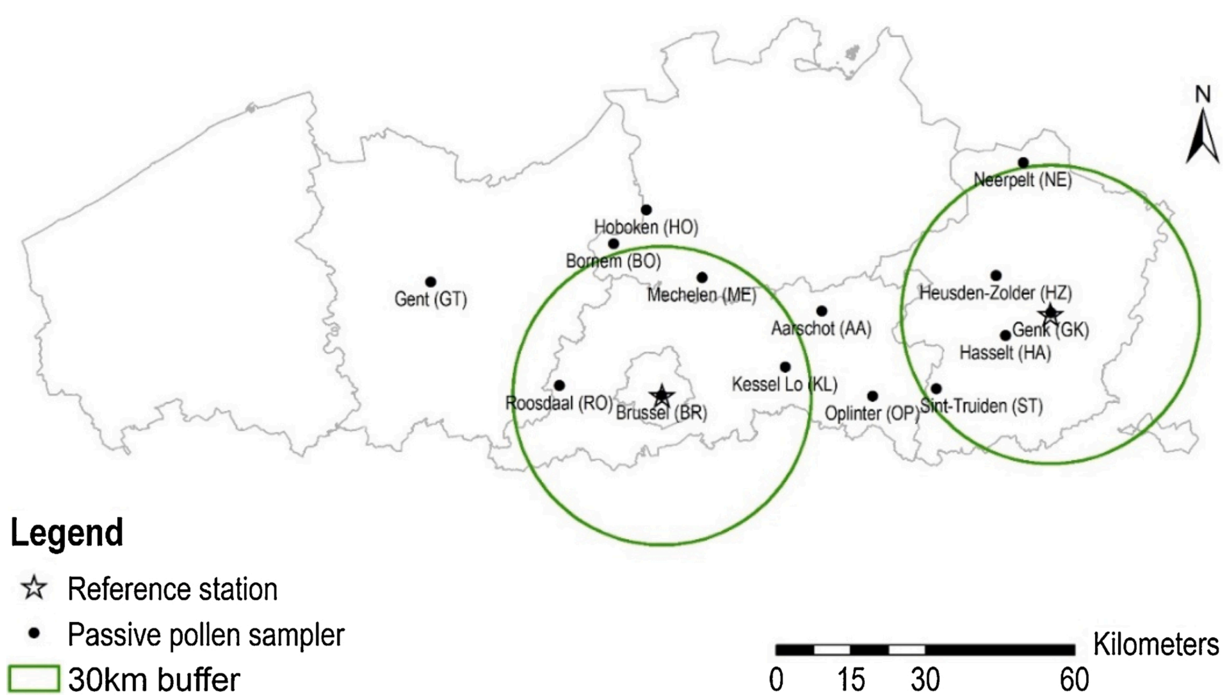



**Fig. 2.** Location of the 14 passive pollen samplers in Flanders and the Brussels-Capital Region (Belgium). The 30 km buffer corresponds to the zone for which the reference stations of Brussels and Genk are representative.

### 2.4. Land cover composition

#### 2.4.1. Land cover data

The surrounding environment was characterized from two land cover data sources available for Flanders. The ECOPLAN dataset (Ecoplan, 2014) is a gridded land cover dataset with a spatial resolution of 5 × 5 m. The Biological Valuation Map (BVM) (Vriens et al., 2011) is a vector-based dataset (cartographic scale 1:10,000) of habitats with information on the type and ecological value of the habitats. Polygon sizes range between 4 $m^2$ and 3236 ha. The mapped polygons are visited by experts in the field to survey the vegetation present to determine specific habitat types. In addition, the presence of remarkable species can be reported as high ecological value. The area fractions (%) of the land cover classes were calculated within six radii (20 m, 200 m, 500 m, 1000 m, 2000 m, 5000 m) around the sampling site using ArcGIS 10.5.1 software (ESRI, 2011). The radii we studied correspond to the meso-gamma scale as proposed by Orlanski (1975), atmospheric processes relevant for pollen transport are studied at this scale (Romero-Morte et al., 2018).

#### 2.4.2. Indirect gradient analysis

For the indirect gradient analysis the site of Brussels was not included, because detailed land cover data was not available for the Brussels-Capital Region. The gradients in the environment are unknown and inferred from the pollen compositions, i.e. an indirect gradient analysis. We used the *envfit* function of the *vegan* package (Oksanen et al., 2019) in the R software (Core Team R, 2017) to correlate ($r^2$) the area fractions with the ordination of the sampling sites.

## 3. Results

### 3.1. Pollen measurements

Pollen of the 12 target tree genera were detected and quantified in concentrations ranging between ~1 to >1000 grains $cm^{-2}$ $month^{-1}$ during the study period (Fig. 3). *Quercus* and *Betula* were measured at all sites in the highest quantities (130–1324 pollen $cm^{-2}$ $month^{-1}$). *Platanus* (13 sites out of 14), *Aesculus* (2 sites) and *Fagus* (6 sites) pollen were the only taxa that were not recorded at all sampling sites.

### 3.2. Comparison of the passive pollen samplers with the reference stations

The passive sampling measurements (lower panels in Figs. 4–6) showed that, for each taxon, pollen peaks appeared during the same

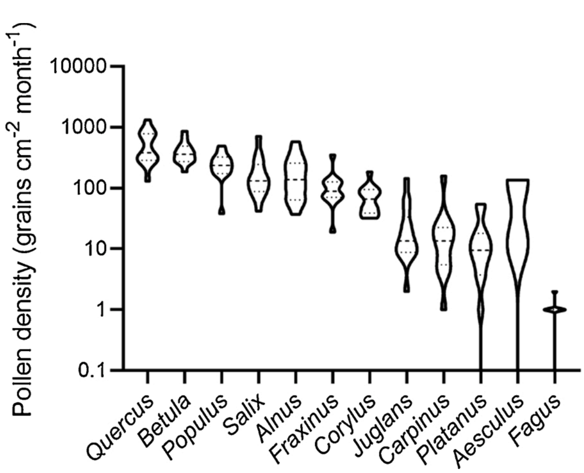



**Fig. 3.** Pollen deposition rates (pollen/$cm^2$/month) of 12 tree taxa measured using Durham-type passive pollen samplers during the 2017 pollen season, at 14 sampling sites in Belgium. Violin plots show the distribution of observations; the y-axis uses a logarithmic scale; horizontal lines represent quantiles.

biweekly periods as in the reference stations with volumetric samplers (upper panels). Results for *Alnus, Betula* and *Corylus* are shown as these taxa are considered the most allergenic in the northern hemisphere's temperate zone (Biedermann et al., 2019; D'Amato et al., 2007; Nowosad, 2016). The passive samplers showed variations in pollen density between sampling sites. During the two week peak periods airborne pollen deposition rates varied: 4–113 pollen/$cm^2$/day for *Alnus*, 28–178 pollen/$cm^2$/day for *Betula* and 5–17 pollen/$cm^2$/day for *Corylus.*

### 3.3. Drivers of the airborne pollen taxa composition

The NMDS ordination result is shown in Fig. 7. The two-dimensional ordination had a low stress-value of 0.11. The airborne pollen composition at each site is presented as a pie chart, showing a large variation among sites and highest abundance of *Quercus* and *Betula* in correspondence with Fig. 3. The pollen taxa that drive the ordination are presented as arrows in Fig. 7. The composition of the landscape around the measuring sites at all the radii (20−5000 m) are given in the supplementary tables S1 (habitats), S2 (habitat value) and S3 (land cover). The most common land cover types are urban land covers and grasslands. Certain less-urbanized sites have more agricultural land cover. The Ecoplan land cover map (Table S3) shows that high green and low green sites are very common. By definition green spaces are classified as high green when the vegetation is taller than 3 m (groups of trees) and low green when the vegetation is shorter than 3 m (grass fields and bush lands, often including *Corylus*) (ECOPLAN, 2014). the BVM habitat map (Table S1) shows high area fractions of small landscape elements (e.g. hedgerows or road verges). Most of the vegetation in Flanders is less-valuable according to the Biological Valuation map, yet several of the sites have high area fractions of valuable and very-valuable habitat (Table S2).

To enhance clarity of the ordination figures (Figs. 7–9) only correlations with a p-value $< 0.1$ are shown. Airborne pollen amounts of *Aesculus*, *Fagus* and *Carpinus* did not contribute to the two-dimensional NMDS ordination of sampling sites (Fig. 7). The other nine taxa were associated with the ordination (p-value $< 0.1$). The airborne pollen composition varied along an urbanization gradient (urban–rural; NMDS axis 1) and a soil moisture gradient (dry–wet; NMDS axis 2) (Figs. 8 and 9). Associations with the habitat types also revealed an ecological value gradient (ecologically valuable–complexes of mixed value) (Fig. 9). Low green and deciduous forests are associated with ecologically valuable habitats. Agricultural fields are associated with ecological complexes of mixed value.

We found no associations for the 20 m buffer zone with a p-value smaller than 0.1 (Figs. 8 and 9). For the 200 m and 500 m zones some associations had a p-value $< 0.1$. Most of the associations with a p-value $< 0.1$ were found for the 1 km–5 km buffer zones (Figs. 8 and 9).

## 4. Discussion

### 4.1. Local variation of pollen composition

Monitoring at the reference stations in Brussels and Genk showed that 2017 was a year of low pollen amounts for *Alnus, Betula,* and *Corylus*. Acording to the Belgian Aerobiological Surveillance Network the pollen season of 2017 was rather weak for these trigger trees (Sciensano, 2017). *Quercus* and *Betula*, two pollen taxa known to be transported over long distances (Maya-Manzano et al., 2017a,b; Skjøth et al., 2015), were measured at all sites in the highest quantities (Fig. 3). Airborne pollen amounts of *Platanus* and *Aesculus* were low and not measured at every sampling site. These exotic ornamental trees are mainly planted along city streets (Pecero-Casimiro et al., 2019) and were thus not present at more rural sampling sites.

In correspondence with previous studies (Piotrowska and Weryszko-Chmielewska, 2003; Teranishi et al., 2006), we found that the airborne pollen amounts measured by Durham-type passive samplers

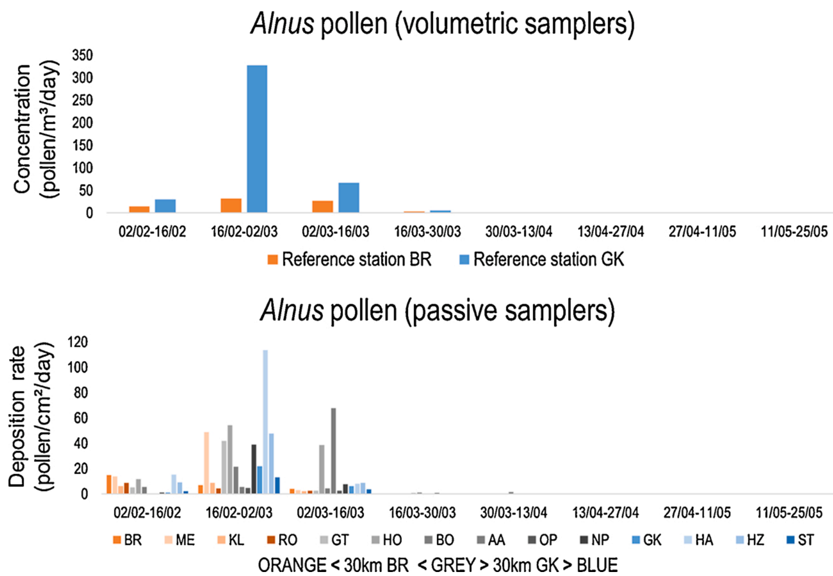



**Fig. 4.** Daily average Airborne *Alnus* pollen concentrations measured by volumetric sampling (pollen/m$^3$/day) at the reference stations Brussels (BR) and Genk (GK) in the upper panel and daily average pollen deposition rates measured by passive sampling (pollen/cm$^2$/day) in the lower panel. Sampling sites within 30 km of Brussels (BR) are shown in shades of orange, within 30 km of Genk (GK) in shades of blue. Sampling sites outside the two 30 km buffers are displayed in shades of grey.

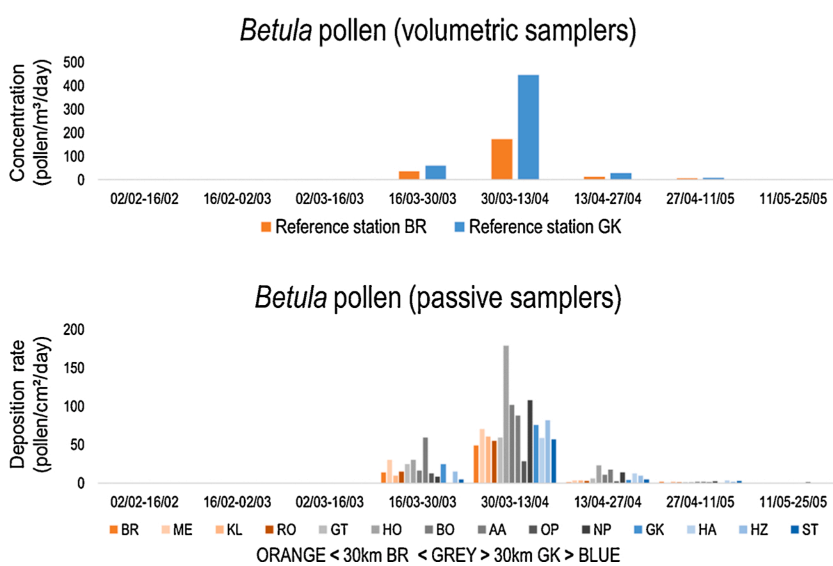



**Fig. 5.** Daily average airborne *Betula* pollen concentrations measured by volumetric sampling (pollen/m$^3$/day) at the reference stations Brussels (BR) and Genk (GK) in the upper panel and daily average pollen deposition rates measured by passive sampling (pollen/cm$^2$/day) in the lower panel. Sampling sites within 30 km of Brussels (BR) are shown in shades of orange, within 30 km of Genk (GK) in shades of blue. Sampling sites outside the two 30 km buffers are displayed in shades of grey.

showed similar taxon-specific distributions over time as the measurements by volumetric samplers (Figs. 4–6). But on top of the general patterns, the passive measurements at 2 m height revealed local variations. Nevertheless, the peak densities at 2 m height were measured in the same period as the rooftop-level measurements, as also demonstrated in a study using 3 samplers and one reference station in south-eastern Poland (Kasprzyk et al., 2019). Rojo et al. (2019) mention that measurements below 10 m are more heterogeneous. This is mostly the case for herbaceous species and some tree taxa, yet not for *Betula* (Bastl et al., 2019; Rojo et al., 2020). The variation in airborne pollen composition is mostly due to variation in the landscape context rather than the measurement height.

### 4.2. Landscape context and pollen composition

The taxa *Aesculus, Carpinus* and *Fagus* did not drive the ordination of sample sites (Fig. 7). *Carpinus* and *Fagus* pollen amounts were extremely low in 2017, possibly due to masting in previous years. *Aesculus* pollen was only measured at two sampling sites located in the bigger cities in the study area, i.e. Gent (GT) and Brussels (BR). The tree originates from the Balkan peninsula, but is commonly planted along lanes in European cities (Thomas et al., 2019). In the Belgian rural areas the tree is not found, explaining the absence of *Aesculus* pollen on the more rural sampling sites.

We found different airborne pollen compositions associated to the surrounding land cover and habitat types (Figs. 8 and 9). The indirect gradient analysis revealed that the secondary axis of the NMDS showed a

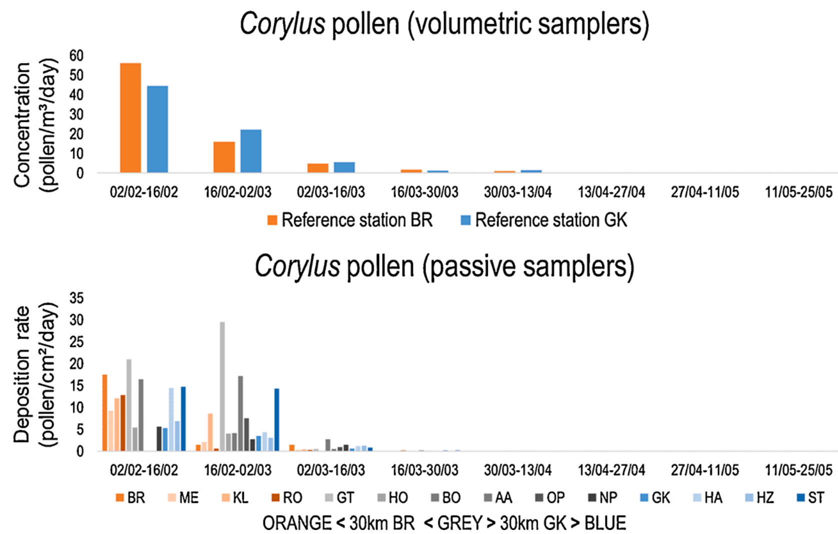



**Fig. 6.** Daily average airborne *Corylus* pollen concentration measured by volumetric sampling (pollen/m$^3$/day) at the reference stations Brussels (BR) and Genk (GK) in the upper panel and daily average pollen deposition rates measured by passive sampling (pollen/cm$^2$/day) in the lower panel. Sampling sites within 30 km of Brussels (BR) are shown in shades of orange, within 30 km of Genk (GK) in shades of blue. Sampling sites outside the two 30 km buffers are displayed in shades of grey.

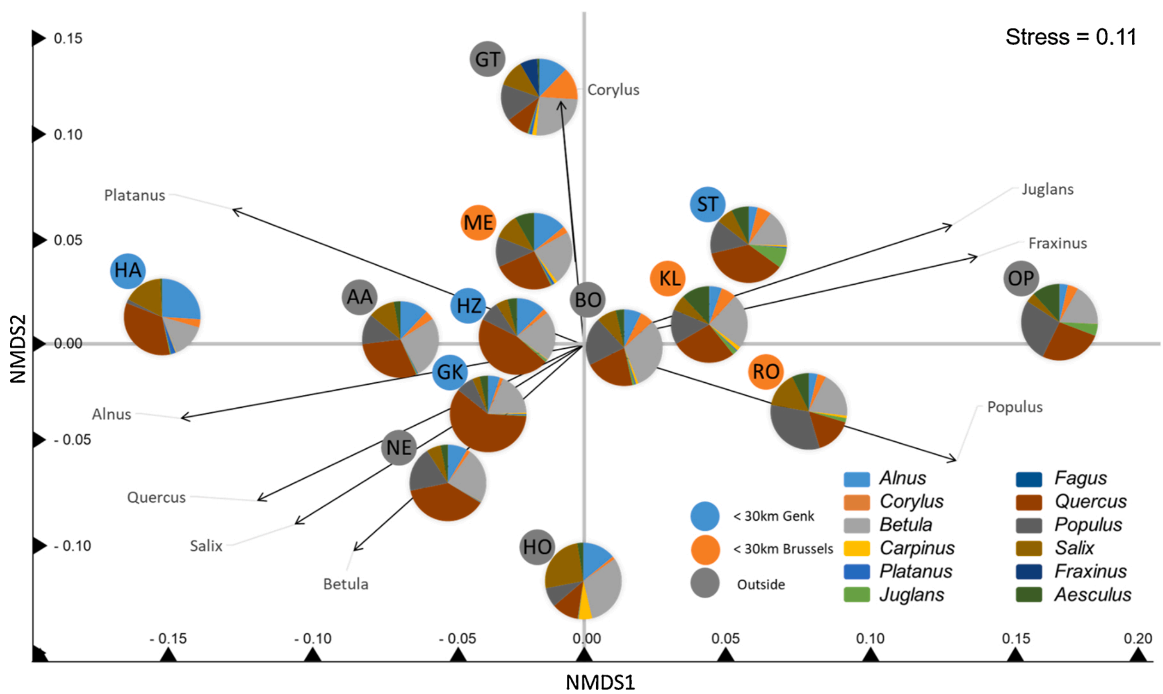
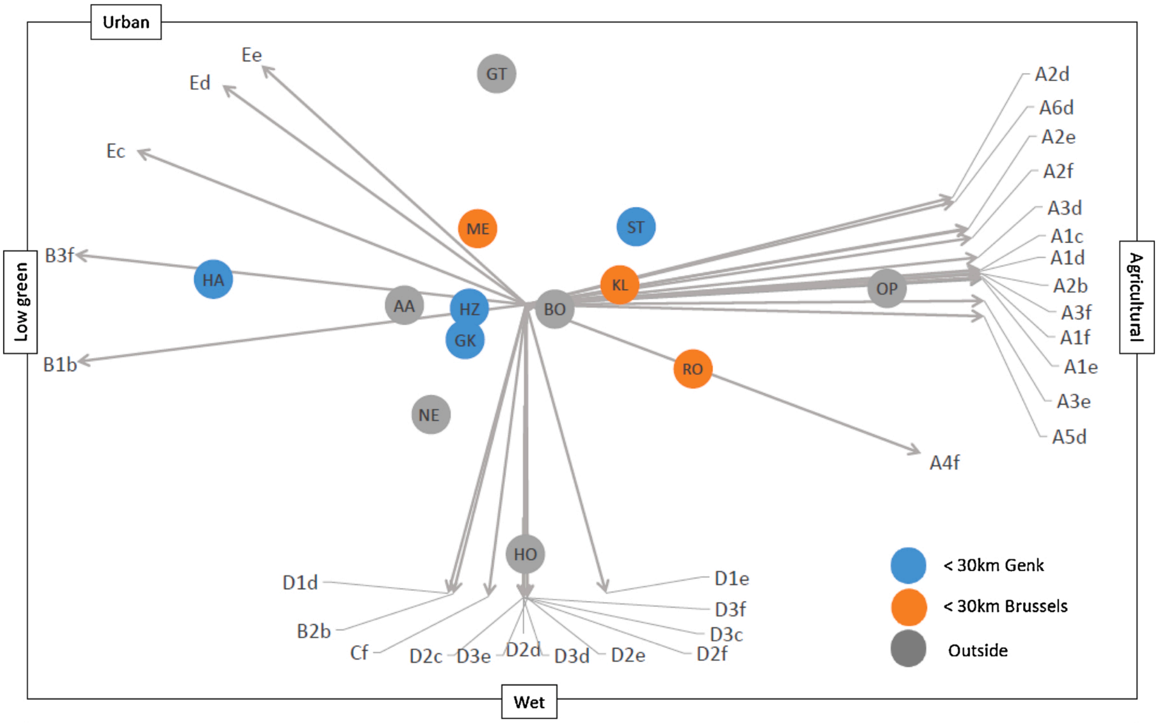



**Fig. 7.** Non-metric multidimensional scaling ordination of the sampling sites based on the airborne pollen taxa composition measured with the passive samplers. The pollen composition is shown in the pie charts.The stress level of the NMDS is 0.11. Key taxa driving the pollen taxa composition at 13 passive pollen sampling sites in Flanders (Belgium). Only correlations with a p-value $< 0.1$ are shown.

strong association with wet land cover types. One of our sampling locations (HO) was located near the Scheldt river. A specific pollen composition including *Betula, Salix, Quercus* and *Alnus* was associated to this riparian landscape context. Kasprzyk et al. (2019) sampled airborne pollen in three parks and found that the river valley probably played a role in the dispersal of pollen (specifically *Quercus* pollen*)* from sources upstream along the river. Similarly, Maya-Manzano et al. (2017a,b) identified riparian forests as sources of *Alnus* pollen in a 10 km radius around their sampling site. In our results, both *Alnus* and *Quercus* pollen were not solely related to wet land cover types, but also to forests (Fig. 7). In Belgium as well as in other European countries, deciduous forests are major sources of airborne *Quercus* pollen (Maya-Manzano et al., 2017a,b; Rojo et al., 2015).

Our results showed that the pollen composition in agricultural areas were characterized by airborne pollen of *Fraxinus, Juglans* and *Populus* (Figs. 7–9). In Belgium, *Populus* and *Juglans* are often present in wood lots or in tree rows along the agricultural fields (Pardon et al., 2019). Similarly, *Fraxinus, Juglans* and *Populus* trees are commonly found along roads in rural areas in Europe (Tóth et al., 2016). Additionally, Rojo et al. (2015) reported that poplar stands commonly occur near rivers and contribute to the elevated *Populus* pollen levels measured in Guadalajara (Spain). We also observed that airborne *Populus* pollen were not strictly




| | Agricultural Land cover | | Low green cover | | Wet land cover | | Urban land cover | | Buffer (m) |
|---|---|---|---|---|---|---|---|---|---|
| A1 | Cereal | B1 | Nutrient rich grassland | D1 | Reed bed | E | Impervious | a | 20 |
| A2 | Sugar beet | B2 | Bush land | D2 | Tidal flats | | | b | 200 |
| A3 | Potato | B3 | Low green | D3 | Salt water | | | c | 500 |
| A4 | Hemp & flax | C | Bare soil | | | | | d | 1000 |
| A5 | Fodder crops | | | | | | | e | 2000 |
| A6 | Orchard | | | | | | | f | 5000 |

**Fig. 8.** Association between local pollen taxa composition and land cover type in Flanders (Belgium) based on non-metric multidimensional scaling. Only correlations with a p-value < 0.1 are shown.

related to the agricultural context but also to wet land cover types (Figs. 7–9). *Populus* plantations are indeed often found on alluvial river valley soils (Smulders et al., 2008).

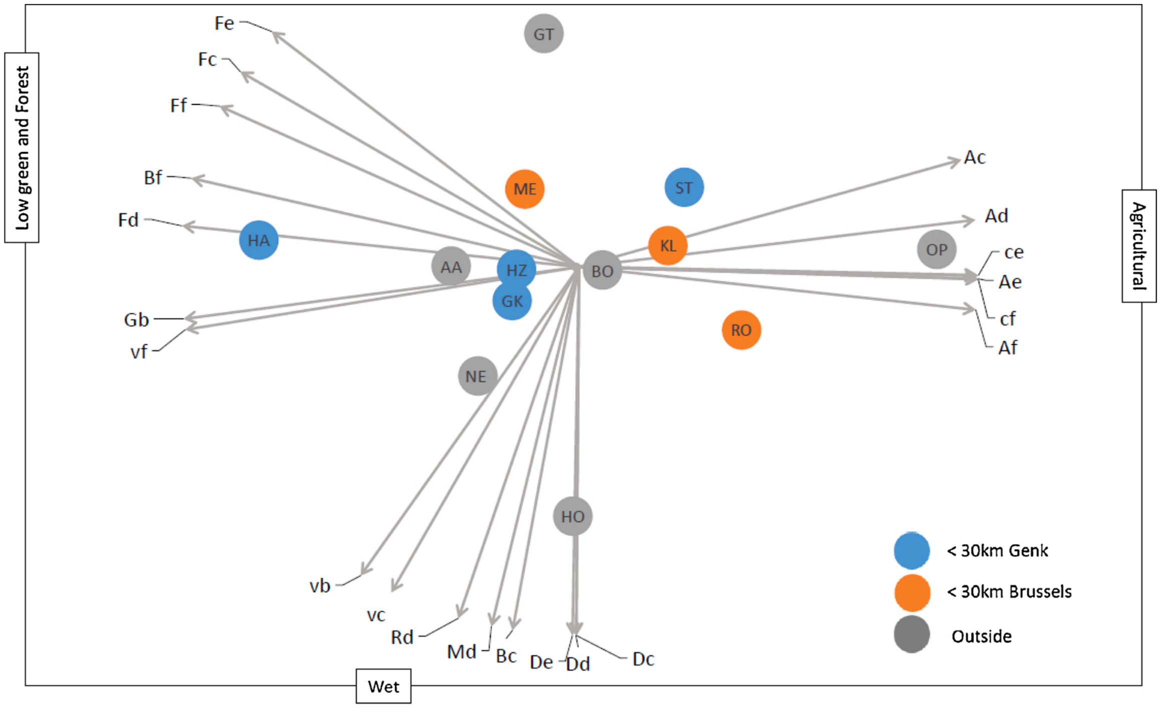
Urban green areas are important sources of pollen as reported in other research (Rojo et al., 2015; Weinberger et al., 2016). In our results, pollen of *Platanus* and *Corylus* were mainly associated with urban landscapes. Rojo et al. (2015) reported that for the city of Guadalajara, parks within a 1.5 km radius of the sampling location were significant sources of *Platanus* pollen. García-Mozo et al. (2016) noticed that increased urbanization has led to increased amounts of *Platanus* pollen in the air in Toledo (Spain). In Western Europe, *Platanus* is commonly used as an ornamental tree, which is planted in urban parks or along city streets (Flora van Nederland, 2014; Selmi et al., 2016). Markedly different airborne pollen compositions have been associated with urban and rural areas. The degree of urbanity has been observed as a determinant of pollen concentration for grasses in Finland (Hugg et al., 2017).

### 4.3. Local pollen scale

We found that local airborne pollen variations are rarely driven by the surrounding landscape at a fine local scale (20–500 m), but rather at a meso-scale (1–5 km). Werchan et al. (2017) reported that fine-scale vegetation sampling in a radius of 100 m around 14 gravimetric pollen traps in Berlin could not explain the differences in pollen abundance. However, within cities, airborne pollen amounts have been found to vary at spatial scales as small as 200 m (Charalampopoulos et al., 2018) and 500 m (Weinberger et al., 2016).

Charalampopoulos et al. (2018) measured airborne tree pollen at 1.5 m height on 6 sites within the city of Thessaloniki (Greece), with an average 2.1 km distance between the nearest sampling sites. They showed that airborne pollen measurements at the 6 sampling sites were more similar than the vegetation within a 200 m radius around the sampling site, indicating that airborne pollen compositions at a given location are not necessarily representative of the land cover composition at that location but rather reflect a mixture from sources found in the wider area. A broader meso-scale would thus be necessary to explain the airborne pollen composition. Indeed, their models showed that airborne pollen measurements were not solely influenced by the vegetation directly surrounding the sampling site (200 m), but also by the vegetation at the nearest sampling site (0.55–5.77 km away) (Charalampopoulos et al., 2018).

Katz and Carey (2014) measured airborne pollen of common ragweed *(Ambrosia artemisiifolia*) across Detroit (Michigan, USA) using 34 Durham samplers installed at 1.5 m above the ground. The pollen amounts were related to vegetation and land use types at both 10 m and 1 km scales. For weeds, such as *Ambrosia* spp., fine spatial scales of 10 m are relevant when measuring at 1.5 m height. For tree pollen, larger scales are probably more relevant. For birch specifically, (Bogawski et al., 2019b) found that pollen concentrations measured at 18 m height were related to crown surface in a 500–1500 m buffer around the pollen trap. Maya-Manzano et al. (2017a,b) found that local airborne *Platanus* pollen compositions were associated with the abundance of Platanus trees within 200–1500 m depending on the wind direction. Our results are thus in line with recent research results, demonstrating that local airborne tree pollen composition is predominantly determined by vegetation and landscape composition at meso-scales (1–5 km).




| Biological valuation | | Antropogenic | | Forest and low-green | | Wet | | Buffer (m) | |
|---|---|---|---|---|---|---|---|---|---|
| c | Mixed value complex | A | Agricultural fields | B | Bushland | D | Dunes and wetlands | a | 20 |
| v | Valuable habitat | R | Roads | F | Forest (deciduous) | M | Marsh | b | 200 |
| | | | | G | Grassland | | | c | 500 |
| | | | | | | | | d | 1000 |
| | | | | | | | | e | 2000 |
| | | | | | | | | f | 5000 |

**Fig. 9.** Association between local pollen composition and habitat types in Flanders, Belgium, based on non-metric multidimensional scaling. Only correlations with a p-value $< 0.1$ are shown.

Nevertheless, we only studied woody plants and these findings might not apply for other pollen types. For herbaceous pollen types smaller local effects have been observed (Peel et al., 2014; Rojo et al., 2020; Skjøth et al., 2013).

### 4.4. Implications

Many studies have utilized smaller radii of 300−500 m to determine residential greenness for human exposure studies (Fuertes et al., 2016; Gernes et al., 2019; Tischer et al., 2017) among others because intra-urban differences in pollen levels have been observed (Hjort et al., 2016; Weinberger et al., 2016). However, we found that local variations in airborne tree-pollen composition were driven by the landscape context at 1−5 km scale. In urban areas, people visiting a park are not only exposed to the airborne pollen in that park, but also to the airborne pollen from the surrounding landscape (Ciani et al., 2020; Pham-Thi et al., 2019). Therefore, pollen exposure data obtained with methods that use larger buffer sizes (1−2 km) are more likely to yield stronger associations with pollen-related health-outcomes (Browning and Lee, 2017; Su et al., 2019).

Green spaces at the edge of the city impact the pollen levels within the city. Species selection should thus be taken into account even in the greenspaces further away from densely populated areas. On the other hand, removing trees with allergenic pollen within cities might have little to no effect given that the local pollen composition is characterized by the vegetation within 5 km.

Further expansion of the pollen monitoring network with samplers at 2 m above ground level might be of interest to study local effects and background concentrations simultaneously. Oteros et al. (2019) show a possible method to select optimal sites for automated pollen monitoring in Bavaria (Germany).

## 5. Conclusion

Passive sampling of airborne pollen demonstrated local variations in airborne tree pollen composition. Urban green spaces, agricultural areas, forests, shrub lands, grasslands and wet land cover types were characterized by marked airborne tree pollen compositions. Associations between local tree pollen composition were driven by landscape characteristics at the meso-scale (1−5 km). The effect of the meso-scale implies that not only green spaces within cities but also around urban areas are expected to influence exposure to allergenic tree pollen within urban areas, potentially affecting the health of a large proportion of the population.

## CRediT authorship contribution statement

**Michiel Stas:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing - original draft, Visualization. **Raf Aerts:** Conceptualization, Writing - review & editing, Visualization. **Marijke Hendrickx:** Conceptualization, Writing - review & editing, Funding acquisition. **Nicolas Bruffaerts:** Conceptualization, Methodology, Writing - review & editing. **Nicolas Dendoncker:** Writing - review & editing, Funding acquisition. **Lucie Hoebeke:** Methodology, Writing - review & editing. **Catherine Linard:** Writing - review & editing, Funding acquisition. **Tim Nawrot:** Writing - review & editing, Funding acquisition. **An Van Nieuwenhuyse:** Writing - review & editing, Funding acquisition. **Jean-Marie Aerts:** Writing - review & editing,

Supervision, Funding acquisition. **Jos Van Orshoven:** Writing - review & editing, Supervision, Funding acquisition. **Ben Somers:** Writing - review & editing, Supervision, Project administration, Funding acquisition.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ufug.2021.127082.

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