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Airborne birch pollen dispersal in an urban setting – case study

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ABSTRACT

An increase in pollen related allergies is anticipated as a result of climate change. This effect is expected to be more pronounced in urban areas that act as heat islands. Although green spaces are intended to mitigate the impact of urban warming, thoughtful greening strategies are required to limit hay fever related symptoms. To integrate pollen exposure of citizens into green space designs and enhance forecasting models and risk maps with finer-scale effects, it is essential to understand the short-range dispersal of allergenic pollen. The aim of this study is to quantify the short-range dispersal of the highly allergenic pollen from the birch (*Betula* spp.) tree and to compare pollen levels in urban situations with varying numbers of birch trees.

To assess these aspects, airborne birch pollen levels were collected with handheld samplers. Pollen levels were compared between three urban localities with none to several birch trees using light microscopy. Additionally, pollen levels were sampled at different distances from a birch tree. The effect of tree distance was tested while correcting for metereological factors. DNA analysis were used to discriminate pollen from the source tree (*Betula utilis*) from background birch pollen (mainly other *Betula* species).

Our findings indicate that pollen levels are significantly higher in streets with multiple birch trees compared to streets with none or a single birch and decrease between 0 and 25 m from the source. Although this is a case study including few locations and it is unknown how these results may be generalized to other urban situations, these results highlight the value of incorporating local pollen sources into fine-scale forecasting models rather than relying solely on pollen concentrations currently taken at rooftop levels. Moreover, given the known adverse health effects of allergenic pollen, our findings suggest that birch trees should be planted at least 25 m away from unavoidable public places such as hospitals and schools while avoiding high densities of birch trees.

1. Introduction

Pollen-induced allergic symptoms currently impact the quality of life of an estimated 30–40% of the European population (Blomme et al., 2013; D'Amato et al., 2007). It is not only a public health concern but also a substantial economic burden. The annual costs per affected individual – including direct expenses and indirect costs such as work absenteeism are estimated at € 961.1 (Cardell et al., 2016). The situation is expected to worsen with climate change, which is projected to prolong and intensify pollen seasons increasing the prevalence and severity of allergic rhinitis and other pollen-related conditions (D'Amato et al., 2020; Katelaris and Beggs, 2018). Over the last decade, the global prevalence of pollen induced allergies has already risen (Savouré et al., 2022). This effect is expected to be stronger in cities because of the urban heat island effect (Voogt and Oke, 2003) and because the share of the population living in cities is expected to increase from 58% in 2024 to 70% in 2050 (World bank group, n.d.). As a result, tree pollen allergy risk in urban spaces is expected to increase by 11–111% depending on the magnitude of changes in tree species composition, allergenic potential and pollen season duration (Aerts et al., 2021).

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Given these developments, there is an increasing need for proactive approaches to mitigate pollen exposure. This includes improved urban green infrastructure planning and the development of high-resolution pollen forecasting models. Thoughtful selection and spatial distribution of vegetation can play a pivotal role in minimizing allergenic pollen load in cities (Calatayud and Cariñanos, 2024; de Weger et al., 2024). Plant species composition in urban green spaces and the link with hay fever is gaining more attention (Cariñanos and Casares-Porcel, 2011; Zhao et al., 2025). Urban green spaces and street-level pollen concentrations can have a large impact on symptomatic responses in sensitive individuals (Cariñanos et al., 2002). Although long-range pollen transport is frequently used to argue against altering local pollen sources, the relative importance of nearby trees for urban pollen levels is still unknown. Understanding pollen dispersal through cities may help to minimize hay fever risks through well designed urban green spaces.

Existing pollen forecasting models are often based on long-range pollen transport and large forests or parks (i.e., SILAM (silam.fmi.fi) (Prank et al., 2013; Sofiev et al., 2013)). Within cities however, a higher resolution model including the effects of smaller patches of urban green spaces is needed.

Pollen concentrations are typically monitored at rooftop monitoring stations across Europe, which serve as a proxy for regional exposure. Although, these measurements generally correlate well with those taken at street level, street-level concentrations tend to be higher and more context dependent (Bastl et al., 2019; de Weger et al., 2020; Rantiolehtimaki et al., 1991; Rojo et al., 2019; Spieksma et al., 2000; Peel et al., 2014). As a result, between different locations within a certain city, pollen concentrations are highly variable (de Weger et al., 2020; Ishibashi et al., 2008; Katz and Carey, 2014; Skjoth et al., 2013; Werchan et al., 2017).

Pollen dispersal over short distances frequently dominates that of long-range transport. For example in Guadalajara, Spain, despite the large area covered with agriculture and forests, urban parks and gardens within 1.5 km from the station contributed most to airborne pollen counts (Rojo et al., 2015). Although, birch pollen can travel long distances (Siljamo et al., 2008) and long-range sources can cause clinically severe pollen concentrations (Bogawski et al., 2019a), small sized urban sources substantially contribute to local pollen concentrations (Bogawski et al., 2019b; Skjoth et al., 2015, 2013). Moreover, for many anemophilic tree species, most pollen is deposited close to the source within 400 m (*Platanus* (Bricchi et al., 2000)), mostly within 50 m *Pinus,* (Adams-Groom et al., 2017)) and for many species within 20 m *Quercus (Pluess* et al.*, 2009; Streiff* et al.*, 1999), Olea* (Lavee and Datt, 1978) *Carpinus, Cedrus, Juglans* and *Platanus* (Adams-Groom et al., 2017).

In Europe, birch (*Betula* spp.) trees are widespread, produce a large amount of pollen per plant specimen (Atkinson, 1992) and the allergenic potential of the pollen is very strong (Biedermann et al., 2019). It is the most allergenic tree pollen in the Netherlands (de Weger et al., 2024) and therefore a main cause for allergic rhinitis. Following grasses — affecting approximately 10–29.5% of the population (Kleine-Tebbe and Davies, 2014) — birch pollen is the second cause for allergic symptoms in an estimated 8–16% of the European population (Biedermann et al., 2019). Consequently, considerable effort has been directed towards modelling and forecasting birch pollen concentrations across Europe (Sofiev et al., 2013; Sofiev et al. 2024). Also for birch pollen, current forecasting models predominantly predict concentrations based on the location of patches of forest, but rarely include the effect of solitary trees or tree rows in urban areas.

In comparison with other tree species (Adams-Groom et al., 2017; Lavee and Datt, 1978; Pluess et al., 2009; Streiff et al., 1999), limited evidence suggests that the concentration of birch pollen peaks at distances further from the source; around 200 m (Yamane et al., 2026). However, in the latter study no measurements were taken at distances between zero and 100 m. Therefore it is important to study the short-range dispersal of birch pollen, especially below 100 m.

Pollen dispersal depends on plant height, settling velocity, wind speed and turbulence (Okubo and Levin, 1989). Some factors seem to be rather constant in their effect on airborne pollen; pollen concentrations generally increase with a rise in temperature, solar radiation and/or hours of sunlight and decrease when relative humidity and rainfall are high (Bonofiglio et al., 2008; Rojo et al., 2015). The effect of other factors is more variable. For instance, wind speed has a significant effect on aiborne pollen concentrations of at least 12 different wind pollinated plant taxa, but the direction of the effect depends on the direction and persistence of the wind and on the species (Damialis et al., 2005). Especially within cities, many interacting factors such as the placement of buildings may alter the effect of wind. Combined effects of wind direction, humidity, and placement of buildings may cause local differences in pollen concentrations compared to roof top level measurements (Peel et al., 2014). Wind direction usually does not seem to have much effect on local pollen concentrations (Pluess et al., 2009). However, in streets lined with buildings, perpendicular wind may cause accumulation of airborne pollen at the windward side of streets despite absence of direct pollen sources (Berkowicz et al., 1996). Therefore, it is important to investigate short-range pollen dispersal in an urban situation while taking into account the various interacting environmental factors such as wind, humidity and temperature. In fine-scale pollen dispersal research, discriminating pollen from the source from background pollen is crucial. A total of eight Betula species occurs in the city of Leiden, the Netherlands (Zachte et al., n.d.). The pollen of these species cannot be distinguished by light microscopy. DNA metabarcoding can provide species-level identification of airborne pollen (Dorst et al., 2026; Polling et al., 2022), which may allow differentiation between pollen originating from nearby trees from less common species (such as *B. utilis* (4.2% of documented birches in Leiden (Zachte et al., n.d.)) from background pollen transported from other species (such as, *B. pendula* and *B. pubescens* 40 and 37% of documented birch trees in Leiden (Zachte et al., n.d.)) that are more common throughout the city.

By focusing on a fine spatial scale, we aim to generate knowledge that supports (i) predictive models, such as hay fever risk maps, that better reflect pollen pressure in cities and (ii) better-informed urban greening strategies. In this study we investigate how birch pollen levels and compositions vary in relation to nearby source trees within an urban environment using spatially distributed pollensniffer sampling and *trnH-psbA* DNA metabarcoding.

Research questions: 1) How much does the abundance of birch trees increase local pollen levels relative to background levels? 2) How does distance from the source tree affect local airborne birch pollen levels and composition within a short-range (≤25 m)?

2. Methods

2.1. Experimental timing and pollen season

Pollen samples were collected at different locations within the city of Leiden between 11:15 am and 15:00 pm in 2025 and between 10:55 am and 12:30 pm in 2026, which is the time of day when birch pollen concentrations are highest (Yamane et al., 2026). Sampling was started based on an estimation of the start of the main pollen season. This estimation was done based on the pollen season start of the past 10 years, the observed ripeness of the catkins and the weather. Indeed sampling took place during the main pollen season including the peak day. The birch pollen seasons were calculated afterwards from the daily measurements of the roof top Hirst type sampler (Burkard Manufacturing Co. Limited, UK) at the Leiden University Medical Center in Leiden. The 95% of the annual birch pollen were measured in 2025 between 01–04 and 19–05 in 2026 between 27–03 and 30–04. The highest number of birch pollen was measured at 04-04-2025 and at 08-04-2026, which both fell within our sampling days.

2.2. Study 1: Effect of tree abundance on pollen levels

Sampling took place on 10 days between 07-04-2026 and 20-04-2026. The first location (Fig. 1a) (52.161,533, 4.470,483), was a residential area with a double stemmed seven m high birch (*B. pendula*) tree and is referred to as the 'single birch'. The second location (Fig. 1b) (52.160,206, 4.492,878), was a shopping street characterized by the absence of birch trees within a 300-m radius, and is referred to as 'treeless street'. The third location (Fig. 1c) (52.171,912, 4.473,257) was a residential area lined with 14 *B ermanii* trees, ~ 7 m high and spaced 5–10 m from each other, further referred to as the 'birch lane'.

One daily sample was taken at each of the three locations by walking down the street 130 m in one direction and 130 m back continuously until 15 min had passed. Samples were taken by three other persons simultaneously at all three locations. All streets sampled had buildings alongside with a maximum of three stories.

2.3. Study 2: The influence of distance, and meteorological factors on pollen dispersal

Sampling occurred on 11 days between 01-04-2025 and 15-04-2025 on two locations. The first location (Fig. 1d) a courtyard at (52.157,409, 4.489,557) had two birch trees (*B. utilis*), which were ~ 0.3 m apart at the base with intertwined branches, making them appear as a single tree. This 7 m high tree is further referred to as the 'entwined birch'. Within the entwined birch location samples were taken at three distances: 0, 10 and 25 m from the tree and in three wind directions: north, east and west. Sampling south of the tree was impossible due to surrounding buildings. The samples were taken by three persons at the three directions simultaneously per distance. The sample at 0 m distance was taken directly under the tree, while walking slowly around the trunk, resulting in a total of seven samples per day at the entwined birch location. The 'treeless street' (Fig. 1b) was also used in this study to get background data on species composition in the city of Leiden. One daily sample was taken at the treeless street location by walking up and down the street walking slowly such that this distance was covered in exactly 15 min.

Each sample was taken with two *Pollensniffers* concurrently to collect at each sampling location duplicate samples with approximately the same pollen in both samples (for more details, see Dorst et al. (2026)). One of the duplicate samples was used for counting the pollen grains (microscopically), the other sample was used for DNA analysis.

2.4. Sampling techniques

Airborne pollen was sampled with handheld *Pollensniffers* (de Weger et al., 2020), each connected to a power bank, which were running for 15 min, sampling 8.3–9.2 l/min (de Weger et al., 2020), corresponding with a total volume of 124.5–138 l of analysed air per sample. Pollen was collected on a Vaseline-coated Melinex strip (Burkard Manufacturing Co. Limited, UK), mounted on a carrier glass-slide. The Melinex strips (for microscopic analysis) were marked with a 12 mm wide circle corresponding with the 12 mm inlet of the device. This provided samples where most of the pollen (estimated 90% (de Weger et al., 2020)) was deposited within the circle. Slides were stained using a gelatine based medium with a safranine colouring agent. During microscopic analysis only birch pollen was counted within the marked circle.

2.5. DNA analysis

Because *Betula* pollen cannot be distinguished reliably to species level using microscopy, we used DNA metabarcoding to identify pollen originating from the entwined *Betula utilis* tree and distinguish it from other *Betula* species present in Leiden. We targeted the chloroplast *trnH–psbA* intergenic spacer, which provides sufficient interspecific variation among *Betula* species occurring in the study area.

DNA was extracted from 88 *Pollensniffer* samples (77 collected near the entwined birch on 7 locations and 11 days and 11 from the treeless street location on 11 days) under clean-room conditions at Naturalis Biodiversity Center (Leiden, the Netherlands). Following pollen exine disruption, DNA extraction, and PCR amplification using plant-specific *trnH–psbA* primers, successful amplification was obtained for 64% of samples. Amplicons were purified, pooled equimolarly, and sequenced on an Oxford Nanopore platform.

Raw reads were processed using a custom bioinformatic pipeline to generate amplicon sequence variants (ASVs). Taxonomic assignment was first performed against GenBank and subsequently refined for *Betula* using a custom *trnH–psbA* reference database. The three most abundant *Betula* ASVs, representing 95% of all *Betula* reads, were retained for

Fig. 1. The sample locations a) the single tree, b) the birch lane, c) the treeless street and d) the entwined tree.

downstream analyses. Full technical details are provided in the Supplementary Methods.

2.6. Meteorological metadata

Meteorological measurements were taken at the entwined birch location during Study 2, using a portable weather station (Kestrel 5400), levelled and calibrated, 0.3 m above ground level at approximately 2 m from the tree trunk. The average wind direction, wind speed (km/h) and temperature were taken over a 15 min time window simultaneous with the pollen samples. The average of the minimum and maximum wind speed was calculated to get a single value per time window. The relative wind direction was calculated by taking the angular offset in degrees between the straight line between the tree and the position where the sample was taken and the vector of the wind, varying from 0 (downwind) to 180 (against the wind). Hourly humidity data was obtained from the closest meteorological KNMI station "215:Voorschoten" approximately 4 km from the entwined birch location. During the measurement period, the daily values varied from 30 to 70%. Local humidity values may differ from those measured 4 km away at the KNMI station; however, the local humidity will largely follow the same trends observed by the KNMI.

2.7. Statistical analysis

Statistical analysis were performed using R-Studio (version 2026.04.0 + 526). Pollen abundance in study 1 was analyzed using a generalized linear mixed-effects model (GLMM) using the glmmTMB and emmeans packages with a negative binomial error distribution (type 2) and a log link to account for overdispersion in the count data. Street was included as a fixed effect, and sampling day was included as a random intercept. Pairwise comparisons among streets were performed using estimated marginal means with Tukey-adjusted p-values.

For the samples at the 'entwined birch' location in study 2, *Betula* pollen from other species than *B. utilis* derived from other sources were statistically excluded from the analysis based on the DNA metabarcoding results. *trnH-psbA* read counts were converted to Relative Read Abundances (RRA). For each sample, we calculated the percentage of *Betula* reads assigned to *B. utilis*. These percentages were then used to correct the microscopic *Betula* pollen counts on a per-sample basis. For samples were we had no exact DNA result for that particular day and location (13%), we calculated the percentage based on the mean percentage at that location and the mean percentage of that day (mean daily percentage x (mean location percentage/100)).

The effect of distance in study 2 was evaluated by comparing nested linear regression models using the glm function from the car package. Model comparison was performed using the anova() function with an *F*-test. This approach tests whether the inclusion of distance significantly improves the explanatory power of the model after accounting for the other predictor variables. A full model containing wind speed, temperature, humidity and the interaction terms (distance × wind speed and temperature × humidity) was compared with a reduced model without the distance term. The interaction between wind speed and distance from the tree was included in the model as the effect of increased wind was expected to depend on the distance from the tree. Additionally, an interaction between humidity and temperature was included since the release of pollen from the catkins is generally triggered by a combination of humidity and temperature (Norrishill and Emberlin, 1991). Graphical inspection of the residual plots confirmed normal distribution of the data. Absolute correlations coefficients between predicting factors were lower than 0.5, rejecting multicollinearity.

3. Results

3.1. Study 1: Effect of tree abundance on pollen levels

Pollen levels differed between streets with no to many birch trees from on average 133 pollen per sample in the single birch location to 193 at the treeless street and 539 at the birch lane. Pollen counts at the single birch location were significantly lower than at the birch lane (Fig. 2, binomial mixed-effects model: $\beta = 2.03$, $SE = 0.40$, z. ratio = 5.15, $p < .001$). Pollen counts at the treeless street location were also significantly lower than at the birch lane ($\beta = 1.72$, $SE = 0.39$, z. ratio = 4.40, $p < .0001$). Between the treeless street and the single birch location, pollen levels did not significantly differ according to the model ($\beta = -0.32$, $SE = 0.38$, z.ratio = −0.85, $p = .675$). Variability between days was substantial (Fig. 3, random intercept variance = 3.00, $SD = 1.73$), indicating that pollen levels differed across sampling days. Remarkably, at the day with peak values in *Betula* concentrations measured at the rooftop (i.e., background pollen levels were high), the differences between the streets were minimal. However, the day that the birch pollen peak at the birch lane, pollen levels in this street were 2.6 times higher than the highest levels measured at the other two locations throughout the study.

3.2. Study 2: The influence of distance, and meteorological factors on pollen dispersal

The levels of *Betula utilis* pollen at the entwined birch location varied on a day-to-day basis (Fig. 4). Wind direction did not have much effect on pollen dispersal (Fig. 5). Wind direction was not used for the samples taken at the 0 m distance, because these samples were taken walking in circles around the stem of the tree, thereby sampling in all directions. In order to quantify the effect of relative wind direction, an initial model (pollen ∼ wind speed + distance + wind direction + humidity + temperature) was tested with only the 10 and 25 m distances. Analysis of this model revealed no significant effect of relative wind direction on pollen levels (lm: $DF = 1$, Type III Sum of squares= 675, $F = .0170$, $p = .89$). Therefore, in subsequent analysis, relative wind direction was excluded from the model.

An interaction effect between humidity and temperature was found with the effect of temperature being stronger at low humidity levels (Fig. 6a). More importantly, when controlling for the effects of meteorological factors on pollen count in a nested model comparison, a significant effect of distance on variation in pollen abundance was found (Partial F-test:$F_{71,67}$= 7.156, P < .0001). Higher pollen levels were found closer to the tree, especially with stronger wind (Fig. 6b).

The mean pollen level of *Betula utilis* close to the tree trunk was 264 ± SD 249 grains/sample. At 10 m from the source, the mean pollen level was 252 ± SD 273 grains/sample. At 25 m the mean pollen count was 57 ± SD 84 grains per sample.

3.3. Proportion of pollen from the local source (DNA analysis, study 2)

Bioinformatics analysis of the trnH-psbA resulted in 9452,423 reads with an average QC score of 21.5. Three dominant Betula ASVs were identified, accounting for 95% of all reads assigned to the genus. The proportions of Betula spp. pollen differed between the locations. At the treeless street, the air sample was dominated by B. pendula/B. ermanii with 92% of the Betula reads. Eight % of the reads was attributable to B. utilis. At the 'entwined tree' location, the sample was dominated by B. utilis (the species present at that location) with 84% of the Betula reads. When averaged over sampling days at the entwined location, B. utilis levels consistently comprised between 73.9% and 100% of the Betula ASV composition in all samples except those collected at the north 25 m position (Fig. 7). At this location, B. utilis accounted for 40.9% of Betula reads, whereas the remaining reads were assigned to B. pendula/B. ermanii. Reads assigned to B. nigra/B. papyrifera were detected only in

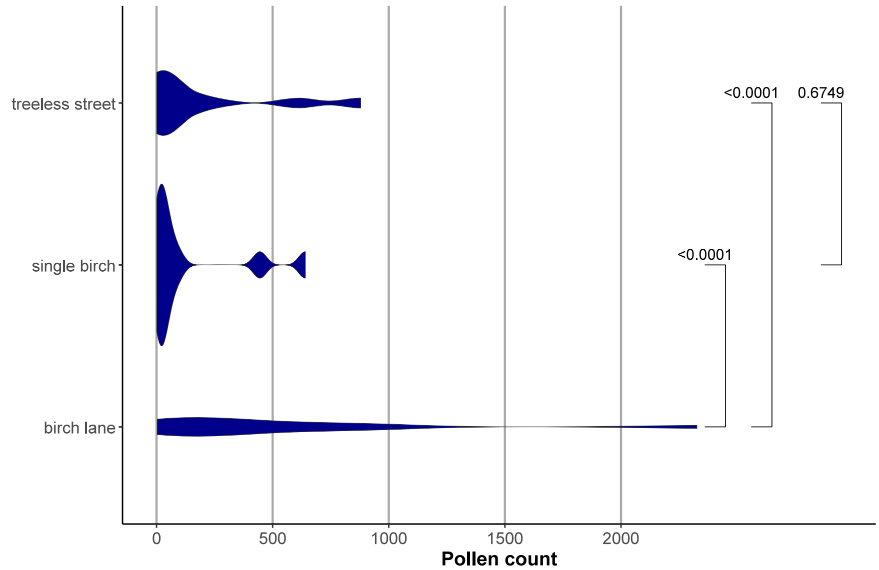

Fig. 2. Violin plots of birch pollen counts per sample. Samples (n = 10 per location) collected at three different locations in Leiden, the Netherlands over 10 days. Significance levels are indicated for a linear mixed model comparing each location with the birch lane.

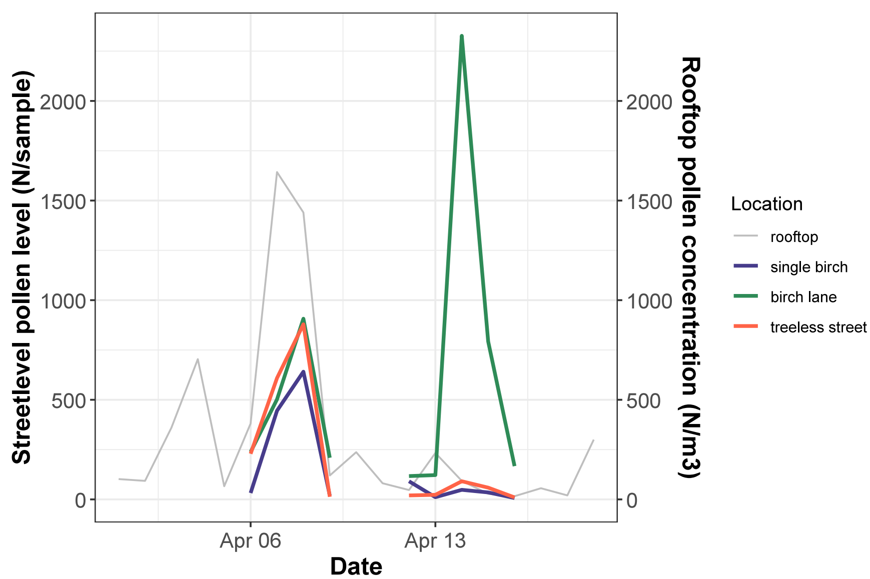

Fig. 3. Birch pollen counts at street level (blue, green and red lines, left y-axis). Rooftop concentrations (grey line, right axis) were taken daily with a Burkard trap, whereas street-level measurements were collected on 10 weekdays in 2026 with handheld *Pollensniffers*.

samples collected directly beneath and to the east of the B. utilis trees.

4. Discussion

4.1. Effect of tree abundance on pollen levels (study 1)

Birch pollen counts at street level differ depending on the number of birch trees present, especially when local birch trees were in full bloom. Our results confirm that planting rows of birches lining streets should be avoided as this causes local pollen peaks which surpass the normal range. Pollen levels hardly differed between the street with a single birch and that without birches. Pollen levels between streets can vary a lot depending on the orientation of the street relative to the dominant wind direction, the presence of high buildings surrounding the street (Berkowicz et al., 1996; Peel et al., 2014), the location relative to nearby birch trees and the number of trees (with or without pollen) present (current study). The single birch location was a street with several other trees which may filter the air, removing some of the pollen. The street is relatively wide, which allows the wind to blow away a substantial amount of the pollen produced by the local tree. In streets with more buildings and less other trees present, pollen levels may be higher. Future studies incorporating multiple streets should investigate the extent to which the presence of local pollen sources influences pollen levels, and how this effect is modified by wind direction and street canyon characteristics. Our results suggest that planting single birch trees in mixed green spaces does not significantly increase pollen exposure compared to backgound levels. Although there were no sources of birch pollen present at the treeless street within 300 m, we found pollen levels comparable with the single birch location during the peak days of the rooftop measurements. The treeless street is directed Northeast (70 degrees), and the wind was 110 and 150 degrees on these days, which resulted in winds perpendicular to the street. These perpendicular winds can cause accumulations of regional pollen in street canyons (Berkowicz et al., 1996; Peel et al., 2014).

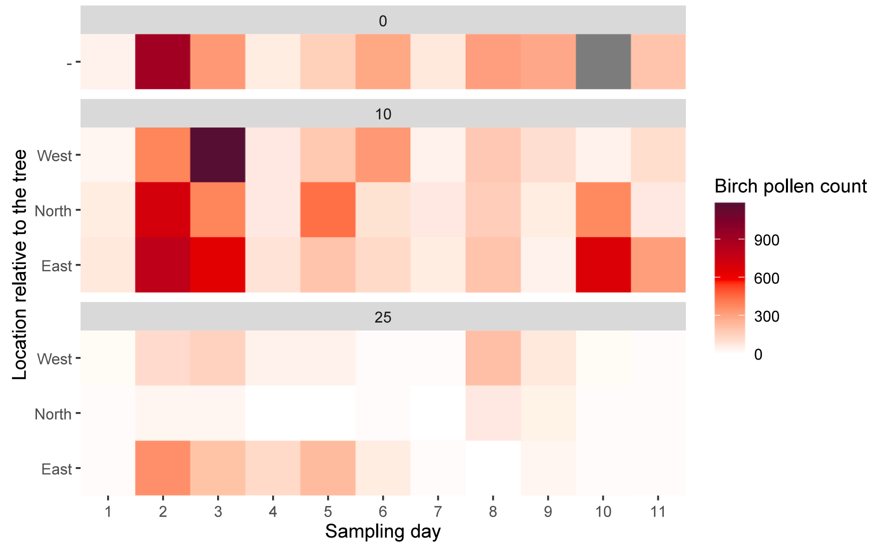

Fig. 4. Heatmap of birch pollen counts at different distances from the entwined birch tree in Leiden, The Netherlands over 11 days in April 2025. Grey fill colour represents missing data.

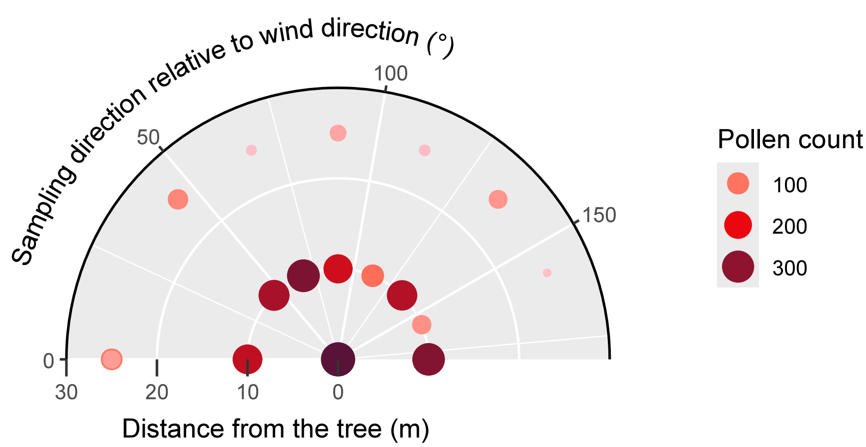

Fig. 5. Schematic representation of birch pollen counts measured at 0, 10 and 25 m from the entwined birch tree in different relative wind directions in Leiden, the Netherlands. The relative wind direction indicates the sampling direction relative to the wind direction measured that day, from 0 (downwind) to 180 (fully against the wind). Pollen counts are means for a given combination of distance and wind direction. Larger darker circles represent higher counts of birch pollen.

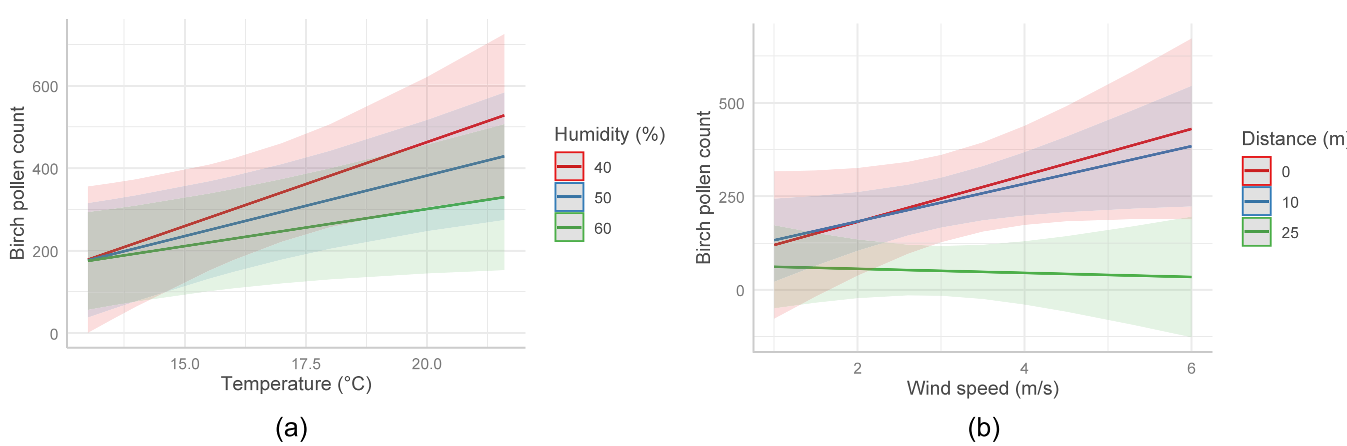

Fig. 6. Predicted values of pollen count according to the model pollen count ~ distance from source * wind speed + humidity * temperature based on the measurements around the entwined birch tree sampled in Leiden, The Netherlands. a) Interaction effect of temperature and humidity on predicted birch pollen levels; b) interaction effect of wind speed and distance from the tree on birch pollen counts.

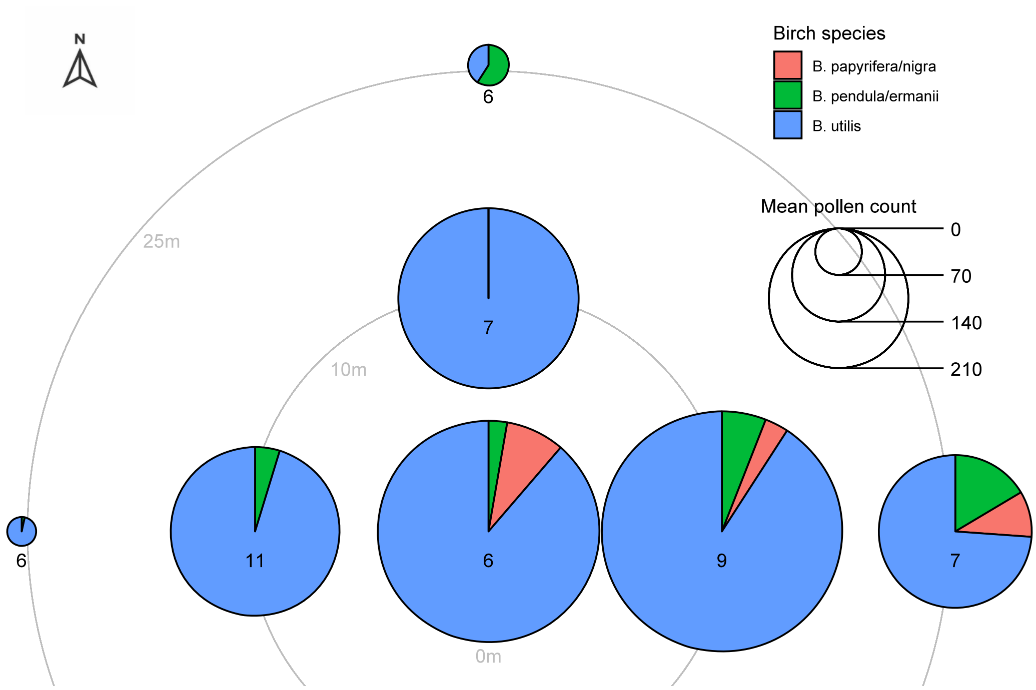

Fig. 7. *Betula* pollen distribution around the entwined birch tree, April 2025. Circle size indicates mean pollen count from 44 (smallest) to 361 (largest circle). Pie graphs indicate relative abundance of *Betula* species based on DNA analysis. Grey lines indicate the distance of the sample location from the source. Numbers in/below the pie graphs indicate the number of samples used for DNA analysis per location.

4.2. Influence of distance, and meteorological factors on pollen dispersal (study 2)

Pollen levels decreased at distances further from the source within a distance of 25 m. This is in contrast with previous findings where birch pollen levels tended to be higher at a 200 m distance from the tree than at a 0 m distance (Yamane et al., 2026). However, it is unknown whether these previously found differences were significant and whether the higher levels were due to pollen dispersal from other nearby sources. Moreover, pollen levels between 0 and 100 m were not measured and may have been higher. Our results are consistent with the higher pollen dispersal at distances up to 20 m from the source found for other anemophilic tree species: *Quercus* (Pluess et al., 2009; Streiff et al., 1999), *Olea* (Lavee and Datt, 1978) *Carpinus, Cedrus, Juglans* and *Platanus* (Adams-Groom et al., 2017). In order to further quantify the relative importance of both short-range and long-range dispersal of birch pollen, both long (>100 m) and short (<100 m) distances should be sampled within one study. Nevertheless, we provide compelling evidence that short-range dispersal plays an important role in airborne urban birch tree pollen concentrations and that pollen concentrations are significantly lower at a distance of 25 m from the tree than at a closer range, especially with stronger wind.

Meteorological factors were found to significantly predict pollen levels. Specifically, pollen levels increased with higher temperatures and wind speeds, but decreased with higher humidity. We found no effect of the relative wind direction. However, conclusions should be drawn with caution. Measurements were collected over just 11 days within a two-week period, resulting in limited variation in meteorological conditions. Consequently, the influence of individual meteorological factors may have been too small to capture substantial effects within our analysis. Despite these limitations, our findings align with previous studies, confirming the established relationships between temperature, humidity, wind and pollen levels (Bonofiglio et al., 2008; Damialis et al., 2005; Rojo et al., 2015). An interesting find is the positive effect of wind speed that was more important at short distances from the tree. This may be linked to the importance of fluctuating wind speed or turbulence on the shedding of pollen from the stamens (Timerman et al., 2014), which occurs more often with higher wind. If most pollen fall down close to the source, these effects may be less noticeable at longer distances.

4.3. Proportion of pollen from the local source (DNA analysis, study 2)

Metabarcoding of the *trnH-psbA* marker enabled distinction between pollen of *Betula* species present in Leiden. The relatively high proportion of *B. pendula/B. ermanii* reads observed 25 m north of the entwined birch is likely attributable to a high abundance of *B. pendula* in background pollen. Indeed, *B. pendula* is highly abundant throughout Leiden, and the DNA reads from the treeless street were also dominated by *B. pendula*. This suggests that the northern side of the entwined birch location was more influenced by pollen from external sources than the eastern and western sides.

Despite the high regional abundance of *B. pendula* trees in Leiden, the low abundance of *B.utilis* and the fact that the entwined bich is the only *B. utilis* documented within a radius of 600 m (Zachte et al., n.d.), pollen collected at the entwined birch (*B. utilis*) location, was consistently dominated by *B. utilis*. Together, these findings suggest that *trn*H–*psb*A metabarcoding of pollensniffer samples can distinguish pollen originating from local trees from background pollen derived from closely related species present elsewhere in the urban environment.

4.4. General discussion and recommendations

Our results stress the importance of short-range pollen transport and local differences for the analysis of highly allergenic birch pollen. This signifies improvement of forecasting models by incorporating short-range pollen transport and local tree abundance rather than relying solely on measurements taken at rooftop levels which generally measure long-range transport and regional concentrations. Street level concentrations, which are representative of what people are exposed to, often differ from rooftop measurements (Bastl et al., 2019; de Weger et al., 2020; Peel et al., 2014; Rantiolehtimaki et al., 1991; Rojo et al., 2019; Spieksma et al., 2000). Therefore, incorporating local pollen sources such as individual urban birch trees and short-range pollen dispersal into high-resolution forecasting models and risk maps may improve the representation of real exposure. This is most important in urban spaces, where an increasing proportion of the population lives and works (World bank group, n.d.) and where pollen concentrations may depend less on remote large forest patches and more on local single sources (Rojo et al., 2015). The development and refinement of high-resolution models will increase the societal relevance of these models by an improved possibility to time precautionary measures to the potential exposure risk.

Furthermore, the insights from this study can contribute to a better design of new green spaces, in the midst of current (re)greening policies, to provide more health and performance benefits for citizens (Hogeweij et al., 2025; Konijnendijk, 2023). Because trees also prevent heat stress and mortality (Iungman et al., 2023), urban planners incorporate them more in their plans, but they should be aware of the risks for pollen allergy. Despite a growing body of research about the advantage and disadvantages of greenness in urban settings (Iungman et al., 2024), the effects of pollen are often neglected (Legg and Kabisch, 2024). When explicitly looking at the effect of pollen, the amount of allergenic pollen in urban green spaces has a negative effect on mental health (Legg and Kabisch, 2024). These negative effects, combined with our results, imply that birch trees should not be planted within 25 m of unavoidable public places such as hospitals and schools. Instead, designers should opt for species with lower allergenicity. Although, pollen exposure can never completely be avoided, merely because long-range pollen transport always causes a certain level of pollen to be spread over a wide area (Bogawski et al., 2019a; Siljamo et al., 2008), these measures will reduce the amount of pollen that people are exposed to. Our results suggest that in this particular case having a birch tree at a distance of 25 m instead of 0–10 m decreased the mean pollen levels with 78%. However, pollen levels were still high during the peak days even at this distance. It would be informative to know at which distance from the source clinical threshold values are less likely to be surpassed. Unfortunately, clinical threshold values have been calculated based on daily pollen concentrations (Steckling-Muschack et al., 2021) or the clinical effects of fixed concentrations are tested in exposure chambers, e.g.,(Ellis et al., 2016) and not in field situations. It is unknown how these values relate to the pollensniffer counts. Nevertheless, it is apparent from our study that birch trees should be planted at least 25 m away from critical locations. Moreover, the current findings substantiate that lining streets with multiple birch trees should be avoided.

Because urban green spaces have a positive effect on citizen health and well-being (Cox et al., 2018), removing trees altogether is not a desirable option. Biodiverse greenspaces including single birch trees, limit birch pollen concentrations to levels comparable to treeless streets. However, caution should be taken with having large birch trees caught between high buildings as in the entwined birch location as pollen concentrations can accumulate in these situations (Fig. 4). Additionally, several methods for allergy free gardening are described (Stevanovic et al., 2025), for example by reducing the number of wind-pollinated plants, replacing allergy rich sources for less allergenic species and avoiding the formation of tight bushes of pollen sources (Cariñanos and Casares-Porcel, 2011). Misogyny, planting female trees only, which is often an effective strategy, does not provide a solution for birch trees as they are monoecious. The quantification of the effects of meteorological factors as well as distance from the source on pollen levels as done in our study will support modelling allergy risk maps of specific cities with various planting schemes. This way, well considered urban green space design may reduce allergy risks in the cities, improving quality of life and health of a large proportion of the European population in urban areas.

4.5. Limitations

The findings of this study are based on a limited number of locations within Leiden, and their generalizability to other urban environments remains uncertain. Nevertheless, while the magnitude of the observed effects is likely to vary depending on local conditions, the overall pattern of lower pollen levels with increasing distance from the source tree and lower tree densities is expected to be consistent across urban settings. A limitation of this study is that only one street was sampled per category. Future studies should include multiple streets within each category to increase replication and improve the robustness of the results.

5. Conclusions

The abundance of birch trees in a street significantly influenced birch pollen levels in urban situations in Leiden. Pollen levels in the street lined with a row of birch trees were higher than those in the streets with one or zero birch trees. However, the presence of a single birch tree did not significantly alter the pollen levels compared to the treeless street. During the peak day of the street with multiple birches pollen levels peaked extremely compared with the other streets. Concentrations on the peak day were 2.6 times higher than the highest levels measured at the other two locations on any day.

Pollen levels significantly decreased at a distance of 25 m from a source tree compared with levels at 0 and 10 m distance.

DNA barcoding turned out to be an effective way of distinguishing pollen from a local uncommon birch species from that from closely related common birch species.

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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.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.tfp.2026.101448.

Data availability

Data will be made available on request.

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