

Are the birch trees in Southern England a source of *Betula* pollen for North London?

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Abstract Birch pollen is highly allergenic. Knowledge of daily variations, atmospheric transport and source areas of birch pollen is important for exposure studies and for warnings to the public, especially for large cities such as London. Our results show that broad-leaved forests with high birch tree densities are located to the south and west of London. Bi-hourly *Betula* pollen concentrations for all the days included in the study, and for all available days with high birch pollen counts (daily average birch pollen counts >80 grains/m³), show that, on average, there is a peak between 1400 hours and 1600 hours. Back-trajectory analysis showed that, on days with high birch pollen counts ($n=60$), 80% of air masses arriving at the time of peak diurnal birch pollen count approached North London from the south in a 180 degree arc from due east to due west. Detailed investigations of three *Betula* pollen episodes, with distinctly different diurnal patterns compared to the mean daily cycle, were used to illustrate how night-time maxima (2200–0400 hours) in *Betula* pollen counts could be the result of transport from distant sources or long transport times caused by slow moving air masses. We conclude that the *Betula* pollen recorded in North London

could originate from sources found to the west and south of the city and not just trees within London itself. Possible sources outside the city include Continental Europe and the *Betula* trees within the broad-leaved forests of Southern England.

Keywords Aerobiology · Back-trajectory analysis · Birch pollen allergy · Source map · United Kingdom

Introduction

Allergic rhinitis is associated with sinusitis and inflammation of the middle ear (Spector 1997), and is closely associated with asthma, suggesting the theory of “one airway, one disease” (Bachert et al. 2004; Grossman 1997). Among people with allergic rhinitis, 20–30% either suffer from asthma or will develop asthma later on (Bousquet et al. 2001; Demoly and Bousquet 2006). Allergic rhinitis and asthma significantly reduce quality of life and have a significant economic impact on society—altering social life, disturbing sleep and affecting performance at school and work (ALK Abelló 2000; Blaiss 2003; Bousquet et al. 2001; Ferguson 2004; Meltzer 1998). The prevalence of asthma and allergic rhinitis has been increasing in Europe since the middle of the twentieth century (Linneberg 2000). However, the relationship between pollen count data and this increase is uncertain at present (WHO 2003).

An estimated 10–20% of the population in Central and Northern Europe are allergic to *Betula* (birch) pollen, where it is rated one of the most important allergenic pollen types (Corden et al. 2002; Oei et al. 1986; Spieksma 1990). The genus *Betula* belongs to the Betulaceae family, which (along with trees from the Fagaceae family) is assigned to

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the order Fagales (APG II 2003). The major allergens of pollen from trees belonging to the Fagales order have a degree of cross-reactivity because they are structurally and immunochemically similar, although the cross-reactivity appears to be strongest within botanically established families rather than between them (Emberlin 1997; Matthiesen et al. 1991; Puc 2003; Rodriguez-Rajo et al. 2004). It has been reported that, at the beginning of the birch pollen season, 90% of patients with birch pollinosis reported mild symptoms above 80 grains/m³. However, during the late season, 80% of patients remained symptomatic at a level below 30 grains/m³ (Emberlin 1997; Koivikko et al. 1986; Viander and Koivikko 1978).

During certain meteorological conditions, birch pollen has the potential to be transported long distances from one region to another (Skjøth et al. 2007; Sofiev et al. 2006). Combined model calculations of atmospheric transport and measurements of birch pollen have shown that long-distance transport affects places such as Fennoscandia (Hjelmroos 1991, 1992) and Denmark (Skjøth et al. 2007) before the local trees start to flower. It has therefore been suggested that *Betula* pollen levels in the United Kingdom (UK) could be affected by long distance transport (Corden et al. 2000, 2002).

Medical treatment for pollen allergy improves the overall health of patients during the pollen season (Bousquet et al. 2001; Demoly and Bousquet 2006; Tripathi and Patterson 2001). In order for treatment to be effective, allergy patients need to be able to plan their medication in advance (Bachert et al. 2004; Sabbah et al. 1999; Stern et al. 1997). This planning requires knowledge of atmospheric pollen concentrations several days beforehand, and so reliable pollen forecasts are needed. Information about possible sources of pollen, including long-distance transport, would increase the accuracy of such forecasts. This paper examines high magnitude *Betula* pollen episodes (2001–2005) during the main birch pollen season in North London (UK), with respect to source regions, using a combination of trajectory analysis and a source map.

Materials and methods

Site information

Betula pollen data for North London were obtained from the roof of the Environmental and Public Protection offices, in the Borough of Islington. Most of the immediate area around the pollen-monitoring site lies below 30 m above sea level but this rises gradually to above 110 m at Hampstead Heath in the north and Crystal Palace in the south. The area is described as mainly urban/suburban. A small proportion of the total land area is semi-natural

vegetation; around 1.6% is secondary deciduous woodland (EA 1999). London is a major city with a complex urban climate, which affects airflow patterns and turbulence, causing micro-climatic changes in temperature. Such factors influence pollen counts spatially and temporally, and are taken into account when analysing aerobiological data (Smith and Emberlin 2005, 2006).

Betula and likely source areas

The genus *Betula* is present throughout the UK and is naturally represented by *B. pendula* (silver birch), *B. pubescens* (downy birch) and *B. nana* (dwarf birch), with *B. pendula* and *B. pubescens* being the most common and widespread (Emberlin et al. 1993; Preston et al. 2002; Stace 1997). Birches usually flower between April and May in the UK. The flowering of birch trees typically occurs at about the same time as budburst (Linkosalo 1999) and before the leaves have expanded (Grime et al. 1996). Birch trees are efficient colonists of disturbed ground. They grow in both dry and damp conditions, *B. pubescens* being more common in moist habitats. Birch trees are also a popular ornamental plant (Dahl and Strandhede 1996; Emberlin et al. 2002). In fact, because of the ornamental planting of birch trees, the size of residential areas around towns and cities is considered to be an important influence on spatial variations of *Betula* pollen levels in the UK, with London experiencing some of the highest birch pollen counts in the country (Corden et al. 2000; Emberlin 1995; Stach et al. 2008). A similar pattern is also found in other countries such as Denmark (Skjøth et al. 2008b).

Betula pollen data

Daily average *Betula* pollen counts from 2001 to 2005 were collected by volumetric spore traps of the Hirst design (Hirst 1952). The methodology used for collecting the *Betula* pollen data in London followed the standard method of the UK National Pollen Monitoring Network described in the British Aerobiology Federation (BAF) guide for trapping and counting airborne pollen and spores (BAF 1995). *Betula* pollen grains were identified to genus level. Daily average (0900–0900 hours) and bi-hourly concentrations of *Betula* pollen are expressed as grains/ m³. The start and the end of the *Betula* pollen seasons were defined using the 98% method (Emberlin et al. 1993), whereby the start is defined as the day when 1% of the season's catch had been recorded, and the end occurs when 99% of the total catch had been reached. Average (2001–2005 mean) diurnal variations in *Betula* pollen counts (bi-hourly values) were examined in order to identify episodes above the critical value of 80 birch pollen grains/m³ daily average. The average of these episodes was calculated, and episodes

that had distinctly different behaviour to the normal daily cycle were chosen for further investigation.

Climate and meteorological data

The British Isles has a maritime temperate climate, with weather that has a tendency to fluctuate rapidly due to the influence throughout the year of low-pressure zones moving in from the Atlantic (Goudie 1996). In London, the mean temperature in January and July is approximately 5.5°C and 18°C, respectively, and the mean annual rainfall is about 584 mm (1971–2000 average; Perry and Hollis 2005).

The overall synoptic weather situation was investigated using observed meteorological data from the London Weather Centre, analysed weather maps from the UK Met Office, and reanalysed meteorological data obtained from the National Centres for Environmental Prediction (NCEP). The analysed weather maps from the UK Met Office and NCEP meteorological fields represent the synoptic situation at 00UTC each day.

Source map calculations

A map of potential sources of birch pollen in Northern Europe (Fig. 1) has been produced using national statistics and forest inventories from the UK (Forestry Commission 2001), France (IFN 2007), Luxemburg (Wagner 2005), the

Netherlands (Paasman 2005; Schelhaas et al. 2006), Germany (Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz 2004) and Belgium (Laurent et al. 2005). The forest inventories were used to calculate the resulting birch tree density in broad-leaved forests using a methodology described in Skjøth et al. (2008a). Detailed land cover information from the Corine Land Cover Classification (European Commission 2005) was obtained from each of the countries as irregular units with a minimum size of 25 Ha and a minimum width of 100 m. The Corine Land Cover classification distinguishes between 44 different land use classes. For graphical purposes, the main source areas have been termed broad-leaved forest. This includes agro-forestry areas, broad-leaved forest, mixed forest and transitional woodland-scrub.

Back-trajectory calculations

Trajectory calculations are based on meteorological calculations from the operational THOR weather and air pollution forecast system (Brandt et al. 2001a, 2001b) using the Eta weather forecast model (Janjic 1990, 1994; Nickovic et al. 1998) and a flexible trajectory model (Skjøth et al. 2002). This trajectory model may be used for analysis of historical data as well as for operational forecasting of back-trajectories 3 days ahead (Hertel et al. 2003). In the trajectory analysis, backward trajectories are used as an indicator of potential source areas according to Stach et al. (2007) and subsequently used by Skjøth et al. (2007, 2008b) and Smith et al. (2008). All times are presented as British Summer Time (BST=UTC+1). Back-trajectories were calculated for all available bi-hourly *Betula* pollen counts within the pollen season ($n=1,664$). Back-trajectories were then sorted using the following two criteria: (1) back-trajectories representing the time of peak diurnal birch pollen count (one trajectory per day) for all available days with daily average *Betula* pollen counts >80 grains/m³ were collected together and examined as a group; (2) back trajectories for bi-hourly counts recorded during episodes with diurnal patterns that were distinctly different to the mean daily cycle were investigated individually.

Results

Source locations map

Broad-leaved forests are found in all parts of North-Western Europe covered by the source map (Fig. 1). In this area, the highest broad-leaved forest densities are found in parts of Southern England, as well as areas of Southern Belgium, France and Germany. Low broad-leaved forest densities are found to the north of London, and much of the Netherlands,

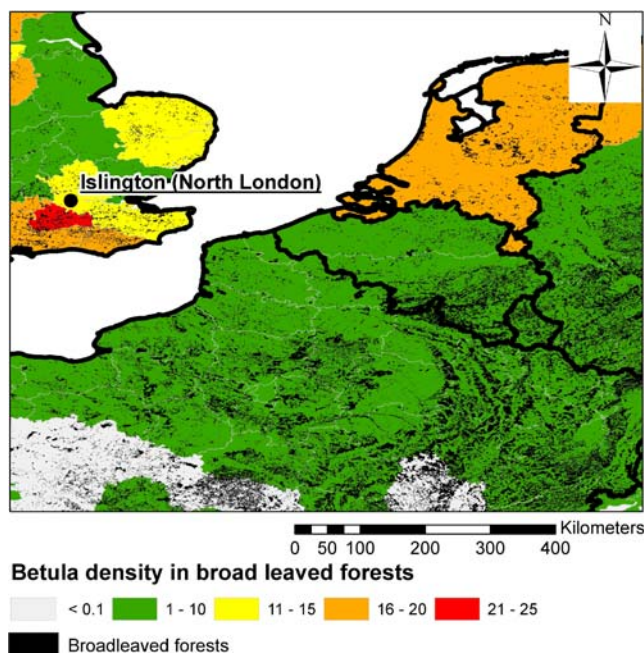


Fig. 1 *Betula* tree density (%) in broad-leaved forests, and the location of broad-leaved forests in Southern England, Northern France, Belgium, Netherlands, Luxemburg and Western Germany

Western Belgium (Flanders) and Northern France. The birch tree density in the broad-leaved forests varies from 0% to 22% between the different regions covered by the source map. Importantly, low densities were found to the north of London, and the highest birch tree fraction of broad-leaved forest (~ 22 %) was found in an area of Southern England to the south of London.

Temporal variations in *Betula* pollen counts

The following statistics refer only to the years covered in this study (2001–2005). The amount of *Betula* pollen recorded in London varied from year to year. The lowest amount of *Betula* pollen recorded annually based on daily average values in the pollen trap in North London was 1,913 grains in 2001, and the highest annual amount was 12,216 grains in 2004. A total of 60 days with daily average *Betula* pollen counts > 80 grains/m³ was found, and the birch pollen season that recorded the highest number of daily average *Betula* pollen counts > 80 grains/m³ was in 2002 ($n=23$). The highest daily average *Betula* pollen count was 1,677 *Betula* pollen grains/m³, which was recorded on 2 April 2002, and the highest bi-hourly *Betula* pollen concentration (5,370 pollen grains/m³) was recorded on 17 April 2004 (1400–1600 hours). Mean (2001–2005 mean) bi-hourly *Betula* pollen concentrations for all the days included in the study ($n=140$), and for all available days with daily average birch pollen counts above 80 grains/m³ ($n=60$), show that, on average, there was a peak between 1400 hours and 1600 hours, which was followed by a gradual decrease in concentrations (Fig. 2). Out of 1,680 bi-hourly observations, 1,644 were suitable for further investigation. Bi-hourly *Betula* pollen concentrations exceeded 1,000 grains/m³ a total of 77 times, and 5,000 grains/m³ on one occasion. Three episodes with high magnitude daily average birch pollen counts and markedly

different behaviour from the normal daily cycle (diurnal maximums between 2200 hours and 0400 hours) were selected for further investigation: 2–7 April 2002, 13–15 April 2004 and 23–25 April 2004.

Back-trajectory analysis calculated at the time of peak birch pollen count

Back trajectories for all available bi-hourly birch pollen counts (2001–2005) showed that 57% of air masses approached from a southerly direction in a 180° arc from due east to due west ($n=1,664$). Back-trajectories calculated at the time of peak diurnal birch pollen count (one trajectory per day) for all available days when daily average *Betula* pollen counts exceeded 80 grains/m³ were examined (2001–2005). A total of 60 back-trajectories were included in the analysis (Fig. 3). The trajectories show that, during the peak time, 80% of air masses approached the pollen-monitoring site from a southerly direction in a 180° arc from due east to due west passing broad-leaved forest areas before arriving in London (Fig. 3).

Specific episodes

Episode 1: 2–7 April 2002

During the period 2–7 April 2002, a series of low-pressure systems (~972–996 hPa) passed to the north and west of the British Isles. From 2–4 April, high-pressure areas (~1,000–1,020 hPa) dominated Continental Europe, but the extent of the high pressure gradually reduced over the 5th–7th. Air masses approached London from Northwest France on 2 April, and from the North and Northeast of France on the 3rd. Air masses from 4–6 April generally arrived from France, Benelux and Germany. On 7 April, air masses arrived from a northwesterly direction, mainly from the Netherlands and the North Sea. Daily average temperatures were between 8.2 and 15.8°C, with maximum daily temperatures reaching 22.5°C on 3 April. No precipitation was recorded.

Daily average *Betula* pollen concentrations increased from 238 grains/m³ on 1 April 2002 to 1,677 grains/m³ on the 2nd. Bi-hourly *Betula* pollen concentrations peaked at 0200 hours on 3 April (3,588 grains/m³). From 3 to 7 April, bi-hourly birch pollen concentrations ranged between 12 and 2,297 grains/m³, with peaks in concentration recorded during the day and again at night (Fig. 4). Back-trajectory analysis shows that on 2–3 April 2002 (Fig. 5a,b) air masses approached North London after passing over Southern England and Northern France. Note that air masses approaching North London between 1800 hours on the 2nd and 0400 hours on the 3rd were over Northern France during the previous day and only spent a few hours

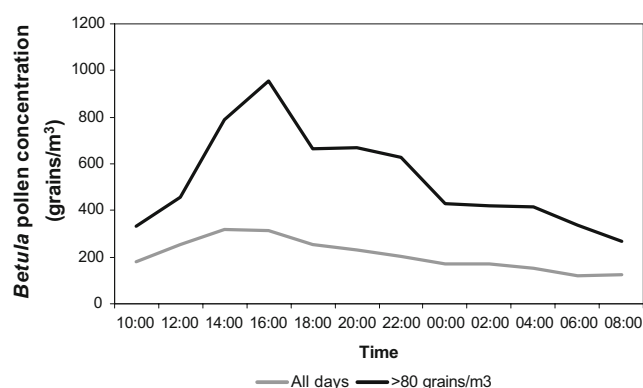


Fig. 2 Average bi-hourly birch pollen concentrations for all the days included in the study; and days with daily average birch pollen counts > 80 grains/m³ (2001–2005)

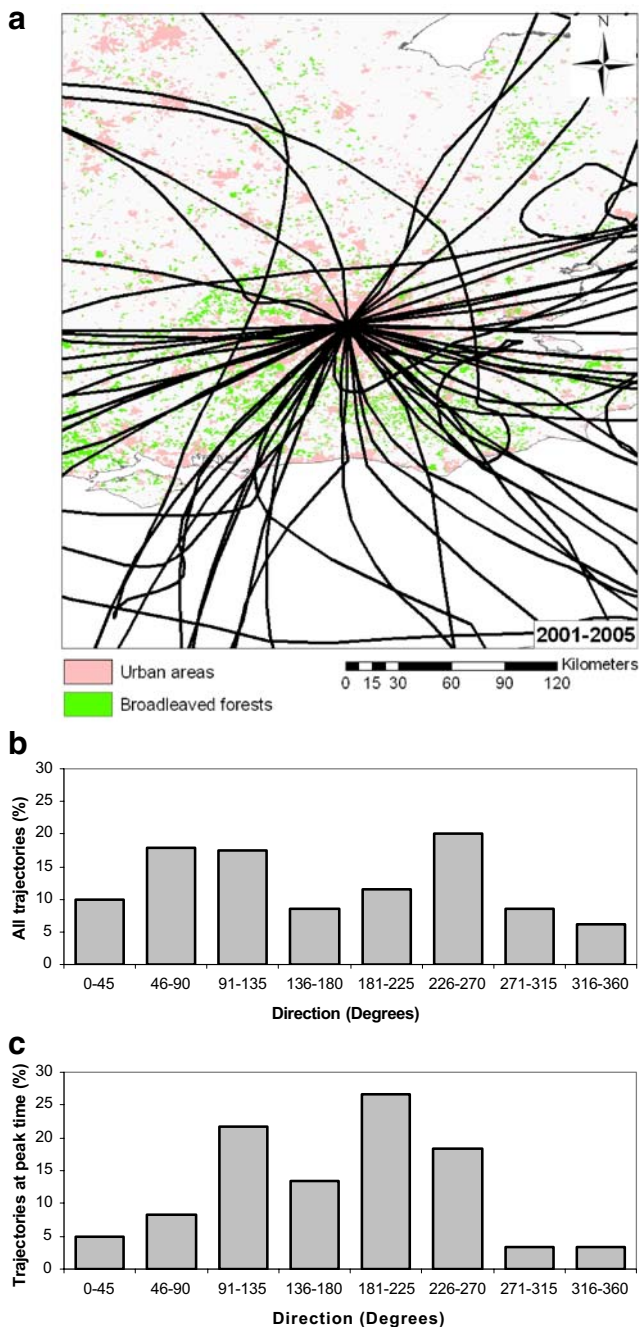


Fig. 3 **a** Back-trajectories run at the time of peak birch pollen count on all days with daily average *Betula* pollen counts >80 grains/m³ from 2001 to 2005 ($n=60$). **b** Percentage of trajectories ($n=1,664$) arriving at the trap in North London (2001–2005) from different directions (45° angles). **c** Percentage of trajectories arriving at the trap in North London (2001–2005) from different directions (45° angles) that were calculated at the time of peak diurnal birch pollen count (one trajectory per day) for all available days when daily average *Betula* pollen counts exceeded 80 grains/m³ ($n=60$)

over Southern England during the evening and night. Back-trajectories for 4–5 April (Fig. 5c,d) show that air masses arrived in London from the east and northeast and were over Belgium and parts of Germany 12–18 h before.

Episode 2: 13–15 April 2004

During the 13–15 April 2004, low-pressure was located over Iceland, while high-pressure was located over Central Europe. Mean sea level pressure (MSLP) over Northern Europe and the south of the United Kingdom decreased from 1,025 hPa to 1,015 hPa during this period. Daily average temperatures varied between 11.7 and 12.7°C, with maximum daily temperatures reaching 17.2°C on 14 April. No precipitation was recorded.

Daily average *Betula* pollen concentrations increased from 507 grains/m³ on 13 April 2004 to 1,081 grains/m³ on the 14th. Bi-hourly *Betula* pollen counts stayed above 300 grains/m³ throughout the afternoon of 13 April, but the

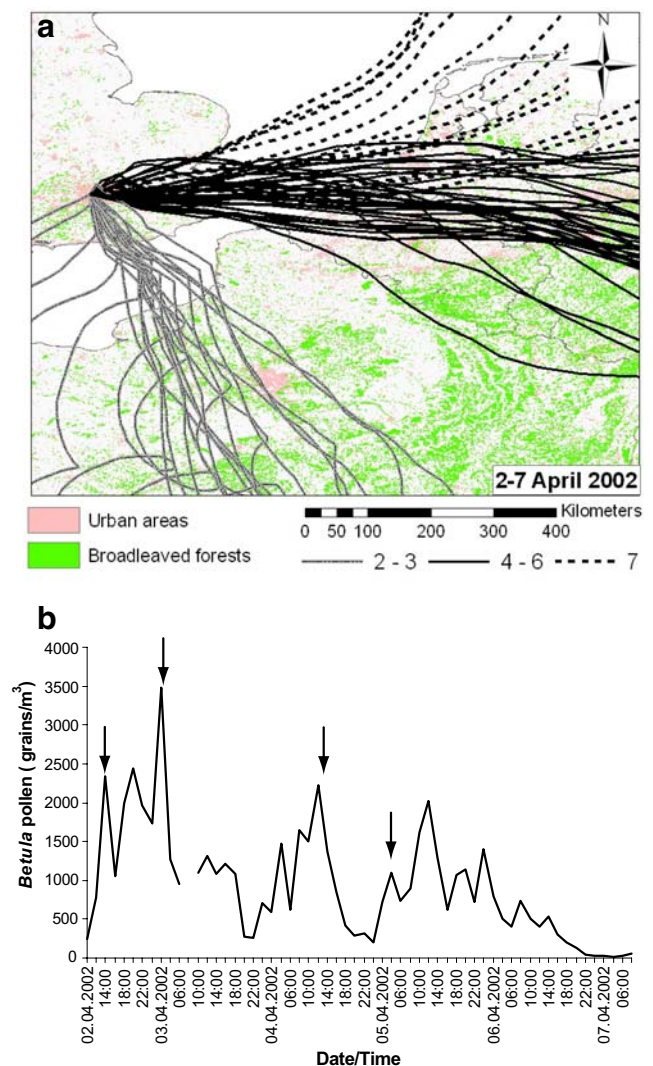


Fig. 4 **a** Back-trajectories arriving at the pollen trap in North London 2–7 April 2002, showing location of possible source areas in broadleaved forests and urban areas. **b** Corresponding bi-hourly *Betula* pollen concentrations (grains/m³) during the episode. Arrows Individual trajectories shown in Fig. 5

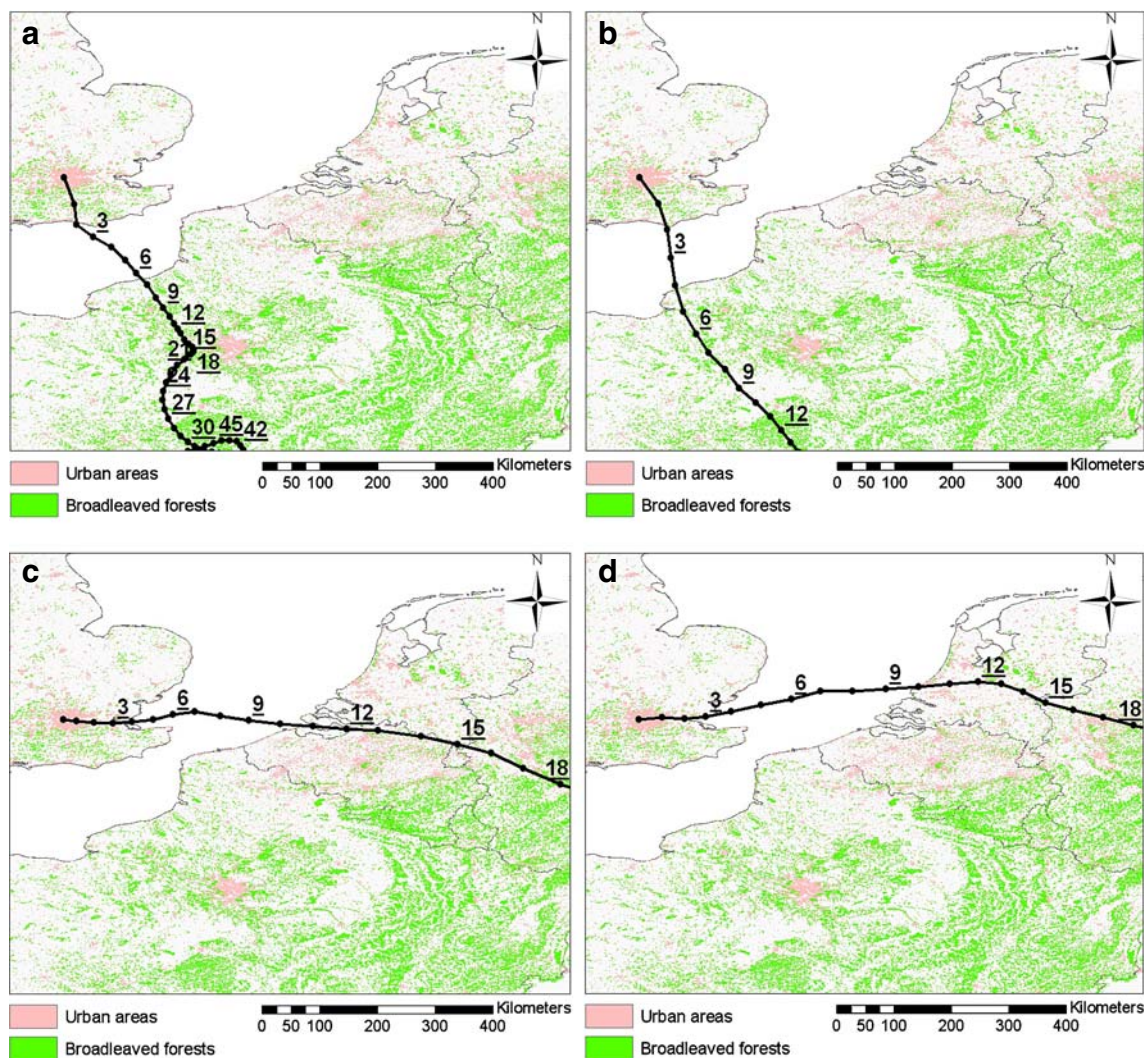


Fig. 5a–d Back-trajectories arriving at the pollen trap in North London, showing location of possible source areas in broad-leaved forests and urban areas at four different times/dates. **a** 1400 hours

British Summer Time (BST), 2 April 2002; **b** 0200 hours BST, 3 April 2002; **c** 1400 hours BST, 4 April 2002; **d** 0200 hours BST, 5 April 2002

diurnal maximum of 811 grains/m³ was recorded at 2200 hours at night. Bi-hourly *Betula* pollen concentrations remained consistently high (> 500 grains/m³) during 14 April, where the pollen concentrations increased to very high values at 1000 hours in the morning and decreased again at 2200 hours. During the day, concentrations reached 1,900/m³ grains or more from 1200 to 2000 hours. The observed peak time was 1600 hours in the afternoon (2,286 grains/m³). Birch pollen concentrations decreased during the evening, and the minimum bi-hourly concentration (102 grains/m³) was recorded at 0200 hours on 15 April (Fig. 6). Back-trajectory analysis (Fig. 7a–d) shows that air masses arriving at the pollen-monitoring site on the afternoon of 13 April approached from the northeast. Air masses then gradually veered to the southeast on 14 and 15 April. Back-trajectories run during the night of the 13th and during the

early morning of the 14th indicate that air masses were over Southern England the previous day. Air masses passing over Southern England around midday on 14 April arrived in London a few hours later.

Episode 3: 23–25 April 2004

On 23 April 2004, weak low-pressure systems were located south and west of Iceland (~986–998 hPa) and high-pressure centres were located over Central Europe (~1,017 hPa) and to the west of France (~1,027 hPa). During the 24–25 April, a high-pressure centre (~1,028–1,029 hPa) moved from the west of France to the North Sea after passing the London area. This high-pressure area caused light breezes between 0 and 3 m/s at the surface. Daily average temperatures varied between 14.3 and

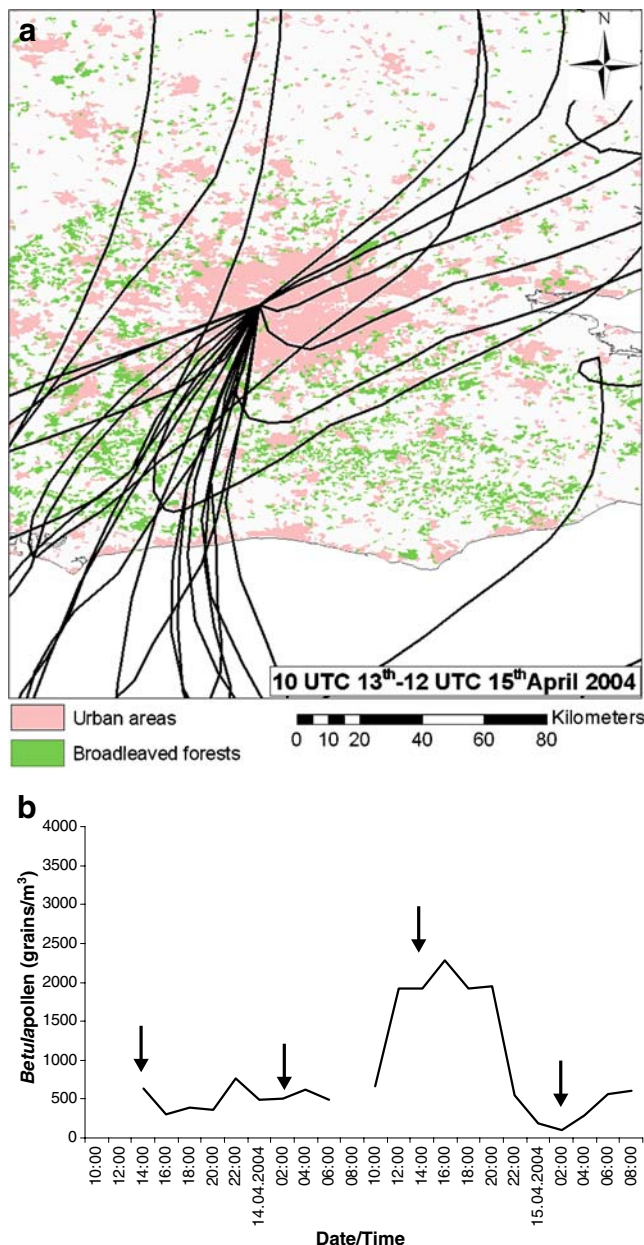


Fig. 6 **a** Back-trajectories arriving at the pollen trap in North London 13–15 April 2004, showing location of possible source areas in broadleaved forests and urban areas. **b** Corresponding bi-hourly *Betula* pollen concentrations (grains/m³) during the episode. Arrows: Individual trajectories shown in Fig. 7

17.2°C, with maximum daily temperatures reaching 23.4°C on 24 April. No precipitation was recorded.

Bi-hourly *Betula* pollen concentrations for the period 23–25 April 2004 (Fig. 8) varied between 18 and 2,622 grains/m³. In general, daytime concentrations were lower than night-time concentrations, with a diurnal maximum recorded at 2200 hours on both the 23rd and 24th (2,622 and 2,175 grains/m³, respectively). It should be noted that the lowest diurnal *Betula* pollen concentration (18 grains/m³) was

recorded at midday on the 23rd. Back-trajectory analysis (Fig. 9a–d) shows that, at the beginning of the episode, air masses approached the trap in North London from the north, but backed to the west, south and southeast as the episode progressed. Back-trajectories also show that the air masses moved slowly, taking 6 h or more to move from the forest areas to the south of London to the trap in Islington.

Discussion and conclusion

London experiences some of the highest *Betula* pollen counts in the United Kingdom, a fact that has been attributed to the ornamental planting of birch trees and the size of residential areas around the city (Corden et al. 2000; Emberlin 1995; Stach et al. 2008). The *Betula* pollen seasons at North London examined in this study (2001–2005) showed a tendency toward biennial rhythms of high followed by low count years—a trend that has previously been discussed in detail (Stach et al. 2008).

The source locations map (Fig. 1) shows that, in the study area, the highest densities of broad-leaved forest, and birch trees within broad-leaved forests, are located to the south and west of London. Back-trajectory analysis showed that, on days with daily average *Betula* pollen concentrations > 80 grains/m³, 80% of air masses arriving at the time of peak diurnal birch pollen count approached North London from the south in a 180° arc from due east to due west. This, combined with a night-time diurnal maximum (2200–0400 hours) suggests that *Betula* pollen recorded at North London could originate from sources found to the west and south of the city and not just from trees within London itself. It should be noted that analyses of all available bi-hourly birch pollen counts during the main birch pollen season (2001–2005) showed that only 57% of air masses arrived from the same direction.

Norris-Hill and Emberlin (1991) showed that the diurnal maximum *Betula* pollen concentration usually occurred about 1800 hours. The results of this study are similar, with a diurnal maximum (2001–2005 mean) being recorded in the afternoon around 1600 hours. Such daytime peaks are likely to be caused by pollen arriving at the trap from sources within, or just outside, the city. Conversely, night-time maximums are likely to be the result of transport from distant sources or long transport times. For example, air masses arriving in North London during the afternoon of 13 April 2004 approached the trap from a northeasterly direction after passing over an area with low densities of broad-leaved forests and birch trees (Fig. 1). Long range transport from the north is a possibility. However, remote areas in the northern UK generally have a later pollen season compared to the London area. This suggests that the *Betula* pollen grains recorded in the afternoon were more

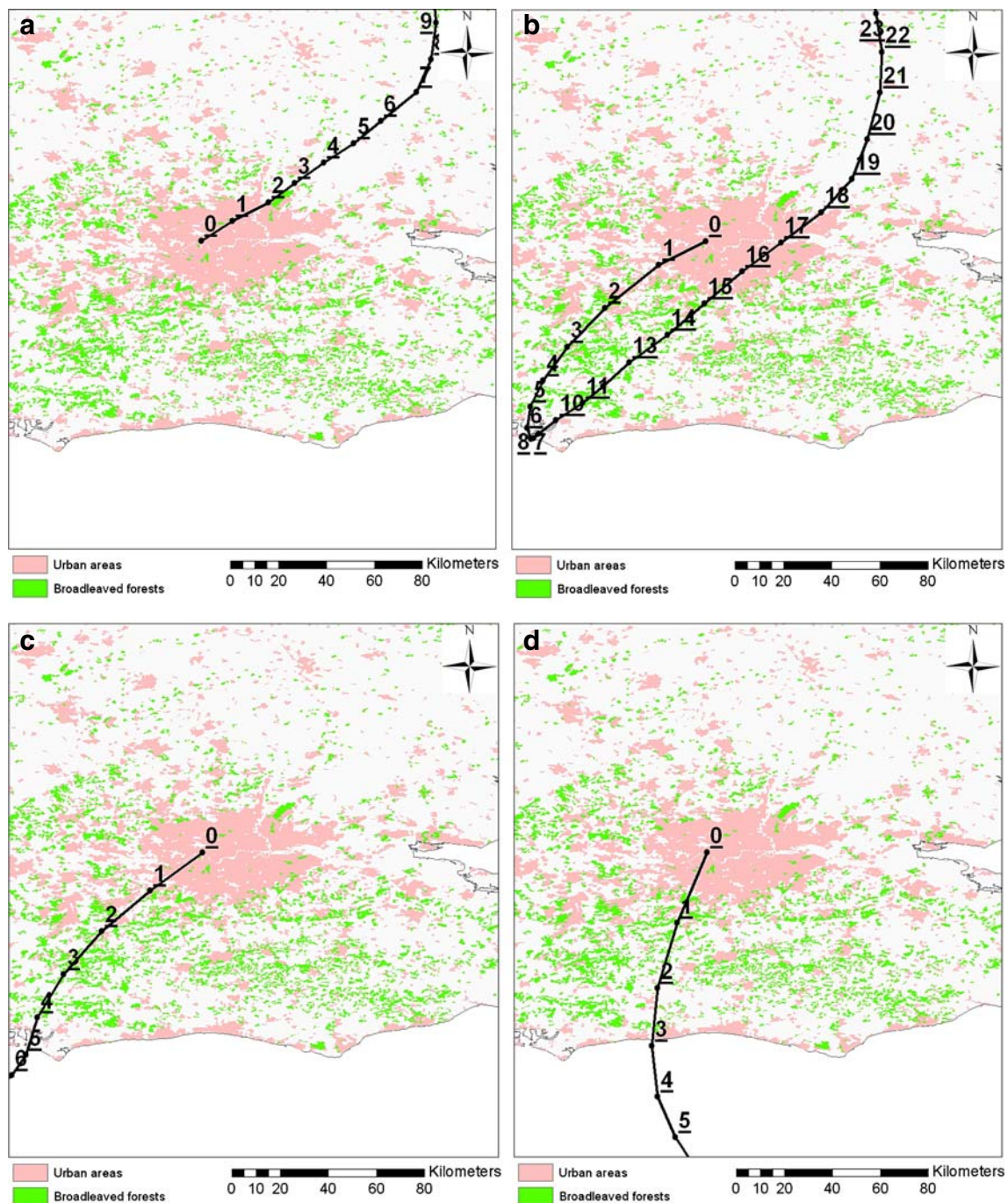


Fig. 7a–d Back-trajectories arriving at the pollen trap in North London, showing location of possible source areas in broad-leaved forests and urban areas at four different times/dates. **a** 1400 hours

BST, 13 April 2004; **b** 0200 hours BST, 14 April 2004; **c** 1400 hours BST, 14 April 2004; **d** 0200 hours BST, 15 April 2004

likely to have originated from areas within or near to the city rather than the limited sources to the northeast, whereas the night-time peak recorded on 13 April, and the high concentrations on the 14th (Fig. 6), were probably caused by the winds veering to the southeast and air masses transporting pollen into North London from the more abundant sources to the south of the city (Fig. 7).

This study has found that the long-range transport of *Betula* pollen to North London from outside of the UK is intermittent, but can result in high bi-hourly and daily average birch pollen concentrations. Episodes of long-range transport identified in this study brought large quantities of *Betula* pollen to the trap in North London during the late evening and night. Bi-hourly *Betula* pollen concentrations

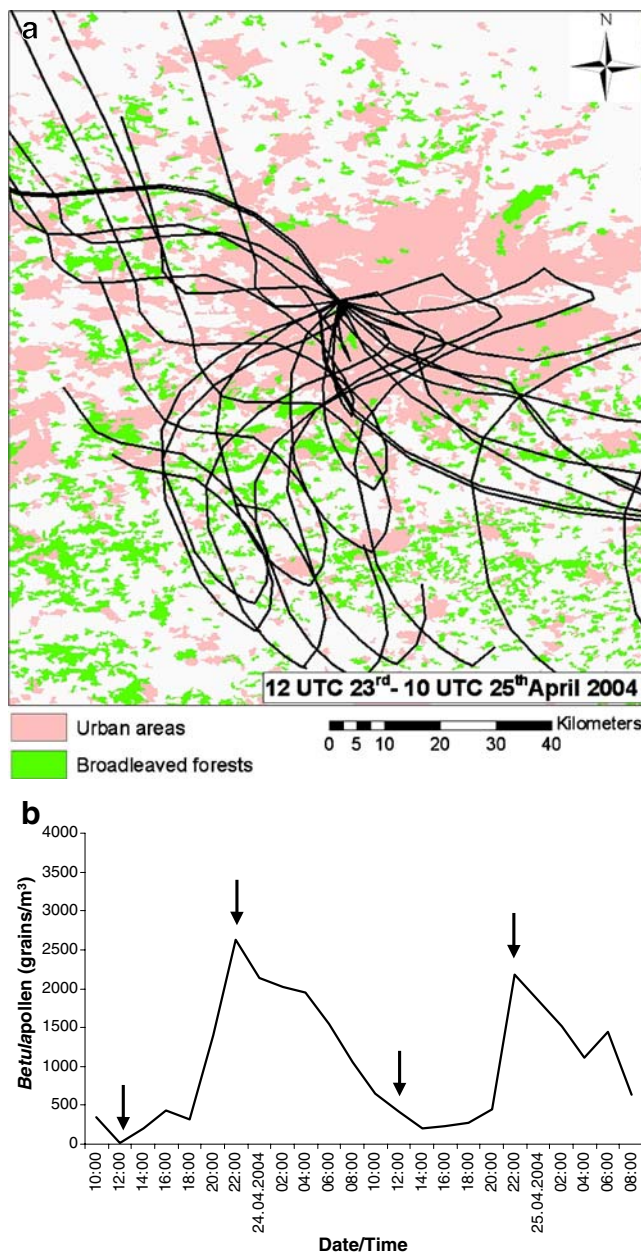


Fig. 8 **a** Back-trajectories arriving at the pollen trap in North London 23–25 April 2004, showing location of possible source areas in broad-leaved forests and urban areas. **b** Corresponding bi-hourly *Betula* pollen concentrations (grains/m³) during the episode. Arrows: Individual trajectories shown in Fig. 9

in the range 1,500–3,500 grains/m³ were recorded a number of times during the episode that occurred at the beginning of April 2002, the likely sources being France and Germany (Fig. 4). Such long-range transport may arrive at any time of the day from more distant parts of the UK or Europe. The long-distance transport of pollen may therefore enhance the contributions from more local sources or result in high night-time concentrations.

Night-time peaks in *Betula* pollen are not always the result of long-range transport. For instance, the high amounts of birch pollen recorded at night during the period 23–25th April 2004 were the result of slow moving air masses taking 6 h or more to cover the distance from the sources of birch pollen in Southern England to the trap in North London (Fig. 9).

Previous studies into the transport of *Betula* pollen have generally concentrated on episodes at the beginning of the season, which occur before local trees commence flowering (Hjelmroos 1991, 1992; Koivikko et al. 1986; Skjøth et al. 2007). Pre-seasonal pollen episodes will have a full allergic impact, as allergy patients are, in general, unprotected during that time. It has been shown that the threshold above which the majority of pollinosis sufferers who are allergic to birch pollen experience symptoms will decrease as the season progresses (Emberlin 1997; Koivikko et al. 1986; Viander and Koivikko 1978). Severe pre-seasonal birch pollen episodes early in the spring may have a similar effect as high magnitude *Corylus* and *Alnus* pollen seasons (the major allergens of pollen from trees belonging to the Betulaceae family cross-react) by priming sensitive individuals, eliciting stronger reactions to birch pollen and effectively extending the birch pollen season (Corden et al. 2002; Emberlin et al. 1997; Rodriguez-Rajo et al. 2004; Valenta et al. 1991).

This study has shown that *Betula* pollen originating from sources outside of London could make a notable contribution to the airborne catch in the north of the city during the main birch pollen season. A degree of caution should be used when examining the results of the source locations map. For example, the map shows that the Netherlands has high densities of birch trees in broad-leaved forest but the fact that the country has only small amounts of broad-leaved forest should also be taken into account when interpreting the map. On the other hand, residential areas in the Netherlands are of considerable geographic extent. Tree cover in city areas may be as high as 20–30 % (Pauleit and Duhme 2000) and *Betula* is reported to be one of the most common road and park trees in Northern Europe (Konijnendijk et al. 2005; Pauleit et al. 2002), thereby contributing to the amount of *Betula* pollen recorded in these cities (Skjøth et al. 2008b). The exact amount of tree cover in cities and the composition of tree species in the Netherlands, Flanders and London is, however, unknown. The map also shows that parts of Northern France included in this study have low percentages of birch trees in broad-leaved forests, but the amount of broad-leaved forest in the region is high.

London has the largest geographical coverage and the highest population of any city in Europe. Therefore, the regular monitoring of biological and non-biological pollutants, and dissemination of information about air quality is

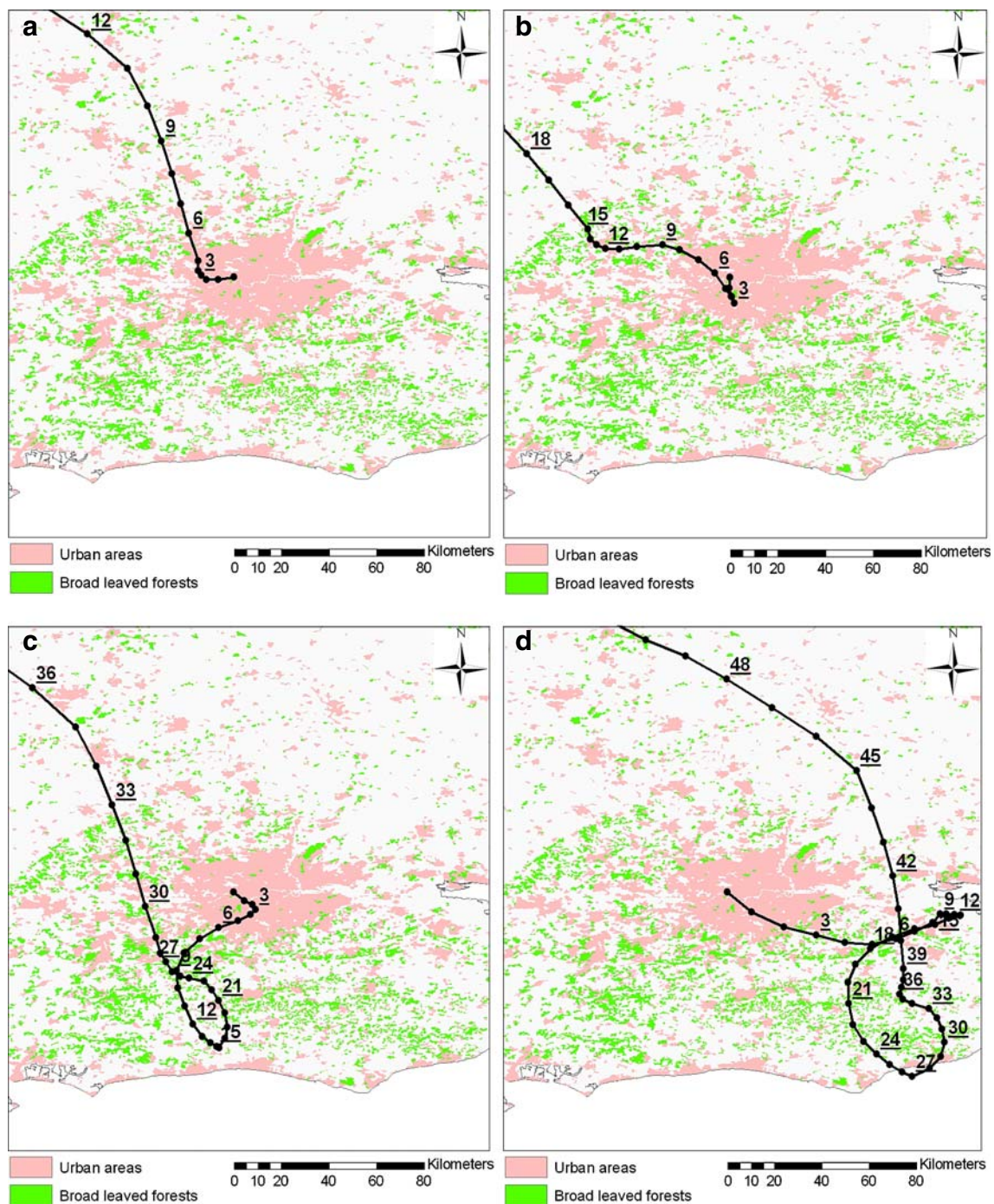


Fig. 9 Back-trajectories arriving at the pollen trap in North London, showing location of possible source areas in broad-leaved forests and urban areas at four different times/dates. **a** 1200 hours BST, 23 April

2004; **b** 2200 hours BST, 23 April 2004. **c** 1200 hours, 24 April 2004; **d** 2200 hours, 24 April 2004

extremely important. The results of this study have shown that bi-hourly *Betula* pollen concentrations (2001–2005) exceeded 1,000 grains/m³ a total of 77 times, and 5,000 grains/m³ on one occasion. These peaks of relatively short duration exceed the daily thresholds of 80 grains/m³ to a large degree. Such short-term variations should be taken into

account in exposure studies and warnings to the public. Furthermore, episodes where birch pollen is transported into the city from outside sources should also be taken into account when considering an individual's exposure to *Betula* pollen. Possible sources outside the city include Continental Europe and, most importantly, Southern England.

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