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Long range transport of beech (*Fagus sylvatica L.)* pollen to Catalonia (North-eastern Spain)

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Abstract

Local and long-range transport of beech (*Fagus sylvatica*) pollen was analyzed by using 23-year data (1983-2007) at 6 stations in Catalonia, Spain, and numerical simulations. Back trajectories and synoptic meteorology indicated a consistent **north** European provenance during beech pollen peak days. Specifically, the area from northern Italy to central Germany was the most probable source, as indicated by a source-receptor model based on back trajectories. For the event with the highest pollen levels (17th May 2004), back trajectories indicated a source in the Vosges **(NE France)** and the Schwarzwald **(SW Germany)** regions. By applying a mesoscale model (MM5) to this event, the pollen transport could be further refined allowing to describe its entrance to Catalonia through the lower easternmost pass of the Pyrenees (the Alberes pass, 500m asl). The hourly counts of the *Fagus* pollen allowed to match the timing of the pollen arrival during this episode with the model results concerning the above-mentioned passage.

This study may help to interpret some results of modern beech genetic diversity and contribute to the understanding of paleopalynological records by taking long-range transport into consideration.

Introduction

Small sized biological material, such as microorganisms, fungal spores, plant diaspores (pollen) and small-size seeds can be suspended in the atmosphere and be transported with the wind. In some circumstances, large pulses are injected in the atmosphere from where they can be dispersed to hundreds of kilometers (Kellogg and Griffin 2006). The entrainment and transport of this biological material to distant places is gaining interest because of its recognized important consequences in: (1) the transport of pathogens, (2) the expansion of the biogeographical ranges of different organisms, and (3) health effects due to the dispersion of allergenic pollen.

For most plant species, pollen plays an important role in shaping the genetic structure of populations (Burczyk et al., 2004) being responsible of gene flow (Ellstrand, 1992; Ennos, 1994), and contribute to the spatially distribution of the species (Ellstrand, 1992; Schmidt-Lebuhn et al., 2007; Sharma and Kanduri, 2007; Smouse et al., 2001). The study of gene dispersal by pollen has important applications on plant biogeography and on plant conservation biology. Therefore, a proper understanding of pollen dispersal is important for the management and conservation of plant species in increasingly fragmented landscapes. Specifically, pollen dispersal is a crucial process in the life cycle of wind pollinated plants.

Many palynological studies have analysed the airborne pollen dispersion. This transport can vary from a mere few meters to thousands of kilometres. To frame the dispersion scale, Prentice (1985) proposed a spatial classification from a local range comprising an area of 20 m radius, to an extra-regional scale for distances greater that 200 km. The long-range transport of pollen and spores implying the extra-regional scales has received much attention recently. For example, it has been demonstrated that viable microorganisms and fungi spores sampled at Barbados (Southern Caribbean Sea) were transported westwards with dust plumes from Africa travelling more than 4000 km (Prospero et al., 2005). Moreover, African mineral dust together with biological material has been sampled in France (van Campo and Quet, 1982) and as far north as Scandinavia (Franzen et al., 1994). Other long range transports, from south to north, are the recordings of “exotic” pollen grains in Fennoscandia originated in the

Mediterranean (Hjelmroos, 1991), and the finding in the artic environment of pollen of trees forming forests at much lower latitudes (Bourgeois, 2000; Hicks and Isaksson, 2006; Rousseau et al., 2003, 2006). Also, particles from long range transport have been found in the Antarctic environment (Wynn-Williams, 1991) and Australia (Hart et al., 2007).

Some recent studies have described the long range transport of allergenic pollen (Cecchi et al., 2006; Hjelmroos, 1992; Stach et al., 2007). Under some circumstances this long range transport may cause pre-seasonal pollen episodes which are currently not included in forecasts based only on local phenological observations, since the pollen may arrive from localities with more advanced flowering seasons (Skjoth et al., 2007). For high allergenic pollen, this poses a difficulty for the protection of allergic patients, and demands that atmospheric transport models that account for long range transport are included in the forecasting schemes.

In Europe, the determination of the origin of airborne *Fagus* pollen is basic to document the beech pollen range of dispersal. *Fagus* pollen could be responsible for allergic manifestations when abundant (Frei and Leuchner, 2000; Heinzerling et al., 2005; Ickovic and Thibaudon, 1991; Lewis et al., 1983). Therefore, the understanding of pollen dispersal is an urgent demand of the European health care system.

In this work, we have concentrated on the pollen dispersal of beech (*Fagus sylvatica* L*)* over Catalonia. Beech is a wide distributed tree across Europe except for most of Spain. The aim of this work has been to analyze the role of long distance transport on the concentrations of the airborne *Fagus* pollen observed in the pollen records from 6 stations across Catalonia (Fig. 1). A case for long-range pollen transport in the Catalan area was already documented for *Ambrosia coronopifolia*, when an unusual condition of atmospheric circulation brought air masses from the area of Lyon (France) where this species is abundant to Catalonia (Belmonte et al., 2000).

To discriminate between the long-range transport of *Fagus* pollen and the local influence, we hypothesized that long distant transport was indicated by simultaneous peaks at the majority of the Catalan monitoring stations, taking into account that *Fagus* plants are not present around most of them. Afterward, we used back trajectories and mesoscale wind movements to describe the synoptic flux responsible for the transport for the days of pollen arrival. Finally, we applied a source-receptor model to infer the probable source regions of the *Fagus* pollen arriving to Catalonia.

Our study may contribute to the interpretation of some of the results obtained on the modern genetic diversity and help palaeopalynologists in understanding their pollen records by taking long range transport in consideration.

Material and methods

Fagus sylvatica L. (European beech) is a large deciduous tree of the Fagaceae family. It is present throughout most of central Europe, including the northern Spanish border, southern Britain, Italy, Balkan, southern Scandinavia and Eastern Europe (Fig. 1). It is usually found on chalky soils and limestones but it is tolerant of a wide range of soils and conditions (Rocha Afonso, 1990). In its northern ranges, European beech represents the dominant species of the lowlands (Puhe and Ulrich, 2001), however, in southern and south central Europe, beech mainly occurs at higher elevations and is often associated with silver fir (*Abies alba).* In Spain it forms dense forests in mountain slopes between 500 and 2000 m under fresh and humid climates with rainfall usually over 1000 mm yr^{-1} (Rocha Afonso, 1990). Where the summer is dry it needs high atmospheric humidity, and spring later frosts are lethal to flowers (Terradas, 1984). In Spain, conditions of humidity and temperature adequate for beech development are only found in the northern mountain ranges (the Pyrenees, Cantabric range) and in some isolated points (North of the Sistema Ibérico, Sistema Central and Puerto de Beceite; Rocha Afonso, 1990).

Beech is a shade-tolerant tree that attains flowering maturity after approximately 40 years of age. Pollination is anemophilous. Male flowers (producing the pollen) are spheroid catkins that appear simultaneously with leaves. In Spain this happens from March to May (Bolòs and Vigo, 2005) or from April to June (Rocha Afonso, 1990). Flowering and fruiting occurs usually in alternate years with a biannual rhythm per tree (annual in some adults) and between 4 to 7 years for the whole forest (Terradas, 1984).

Pollen record

Pollen data were recorded at 6 monitoring stations across Catalonia, NE Spain: Barcelona, Bellaterra, Girona, Lleida, Manresa, and Tarragona (Fig. 1). Samples were obtained weekly from a Cour sampler (Cour, 1974) for the period 1983-1995, and daily from a Hirst sampler (Hirst, 1952), the standardized method in European aerobiological networks, from 1996 onwards. The total recording period was 23 years, from 1983 to 2007 both included (except for years 1986 and 1987). Details of the sampling schedule at the different locations are shown in Table 1. Because of the seasonal character of the pollen emission, linked to flowering, pollen counts used in this paper comprise the period from 1st March to 1st July each year.

Pollen peak identification

By analyzing the complete temporal series of daily data, one can conclude that years 2004 and 2006 presented outstanding *Fagus* pollen concentrations (Table 2). Annual indexes presented an absolute maximum in year 2004 at all sites and a second maximum in 2006, in 4 out of 6 sites (Table 3). For this reason, these years were analysed in more detail: each monitoring station was screened to detect the peaks of pollen arrival by using a paired t-test that compared pollen counts between consecutive days. Moreover, the complete data set was screened to identify the dates of maximum absolute concentration (see Table 2).

Atmospheric transport

The provenance of the air-masses transporting pollen was examined with backward atmospheric trajectories. Isentropic 96-h back-trajectories at 1500 m above sea level (asl), starting at 12 UTC from the coordinates of each monitoring site or from a central point of the Catalan geographical area (41.8º N, 1.5º E) were computed using the Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT-4) of the National Oceanic and Atmospheric Administration (NOAA) (available at http://www.arl.noaa.gov/ready/hysplit4.html, Draxler & Rolph 2003) from the gridded meteorological fields of the FNL archive data. The trajectory origin was classified according to the area crossed by the backward trajectories as coming from Africa (AF), the Mediterranean (ME), the Iberian Peninsula (PE), Europe (EU) or the Atlantic Ocean (AT).

The *Fifth-Generation Pennsylvania State University/ National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model* (MM5) (http://www.mmm.ucar.edu/mm5/mm5-home.html) was used to simulate some specific meteorological situations corresponding to days with exceptionally high pollen levels. MM5 is a limited-area, non-hydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale atmospheric circulation (Dudhia, 1993, Grell **et al.** 1994). Initialization and boundary conditions were updated every 6 hours from the analysis data of the European Centre for Medium Range Weather Forecast (ECMWF). The meteorological simulations were performed using three nested domains with 9, 3 and 1 km horizontal resolutions. For this specific situations, back trajectories were computed from the velocity fields obtained from the MM5 inner domain simulations (1x1 km^2 resolution, Fig.1) using a purely kinematic trajectory model (Alarcón et al., 1995).

Source areas

A statistical approach that combines pollen concentration data at the receptor stations with backward trajectories ending at these sites was applied to infer the source areas for the pollen reaching the Catalan stations. Such source-receptor methodologies establish a relationship between a receptor point and the probable source areas by associating each value of pollen abundance with its corresponding back-trajectory. A grid with 2601 cells of 1º x 1º latitude and longitude was then superimposed on the integration region of the trajectories in order to map the contributing points.

We applied the Seibert methodology (Seibert et al., 1994) in which a logarithmic mean pollen concentration is computed for each grid cell based on the residence time of the trajectories in the cells:

$$\log C_{ij} = \frac{\sum_{l} n_{ijl} \log C_l}{\sum_{l} n_{ijl}}$$

where C_{ij}: is the mean concentration in the (i,j) cell, l is the index of the trajectory, n_{ijl} is the number of time steps of the trajectory l in the cell (i,j), and C_l is the pollen concentration measured at the receptor point corresponding to the trajectory l. For this calculation, daily back trajectories from 1st April to 30th June for the 10-yr period 1997-2006 (720 trajectories) were used. Segment end points corresponded to 60-min time steps (69120 end points). The accuracy of the methodology increases with the number of ending points considered, therefore we used the maximum meteorological data available for the calculations (period 1997-2006). To minimise the uncertainty of the trajectories, a smoothing method was applied and the value of each cell was replaced by the average between the cell and the eight neighbouring cells. Finally, a filter was applied to exclude cells with less than five time-steps. The abundance field map obtained in this way reflects the contribution of each cell to the abundance at the receptor point.

Results and discussion

Peak dates and wind trajectories

Table 2 shows that the dates of yearly absolute maximum concentrations at the Catalan stations for the whole study period have predominantly North wind trajectories.

By considering only the data obtained with the Hirst samplers (daily basis), years 2004 and 2006 presented the highest *Fagus* pollen concentrations in the whole 14-yr recording period (Tables 2 and 3). Therefore, these two years were selected for a more detailed study. The temporal variation of the mean daily pollen concentrations in 2004 and 2006 for the 6 recording stations is shown in Fig. 2. During 2004, all Catalan stations presented the highest mean daily pollen concentrations on the 16-17th May. For 2006, most of the stations presented the largest concentrations during the period 26th - 29th April.

Synoptic flux and back trajectories were used to infer the origin of the air masses reaching the stations during these particular days (Table 4). During 2004, all peak days, except for the 9th and 30th May, presented air fluxes originated in **north** Europe. For wide coverage events (e.g. when peaks were detected simultaneously in 3 or more of the Catalan stations, as in the 25th April, 12, 13, 14, 16 17, 22, 24 and 27th May 2004), all the back trajectories were originated in **north** Europe (Table 4). On the contrary, during 2006, the pollen peaks were associated to more diverse provenances: **northern** European air mass fluxes (31%) and Mediterranean (34%) presented similar frequencies, while Atlantic and Peninsular back trajectories accounted only for 17% and 14%, respectively of the peak days. Nonetheless, for broad scale events covering 3 or more stations, the dominant quadrant was again **northern** European (75% of the cases; see Table 4).

In order to study the influence of local vegetation on the pollen records, Girona and Barcelona stations were examined in more detail. Contingency table tests indicated a significant association between pollen peaks and European provenance at Girona for both years (Table 5). At Barcelona this association was only significant for year 2004, where 100% of the peak events corresponded to European air masses. In year 2006, only 6 pollen peak events were recorded in Barcelona, 50% of them with a European origin (Table 5).

The above lines of evidence suggest that peak days of *Fagus* pollen in the Catalan stations are associated with **northern** European air masses. However, to better describe the transport, an outstanding pollen event on 16-17th May 2004 was studied in more detail.

16 and 17 May 2004 episode

During this event, all of the Catalan monitoring stations recorded a very important pollen peak (Fig. 2), with values up to 90 grains/m^3. These represent the highest mean daily concentrations in the whole 23-yr record. The synoptic situation during this episode was characterized by a high pressure nucleus over the British Islands and a low pressure centre to the east of the Scandinavian Peninsula (Fig. 3a). This resulted in a synoptic circulation with prevailing south-westward winds from the central Europe to the Iberian Peninsula. The Hysplit back trajectories for this event showed that the air mass followed the corridor between the British high and the eastern Scandinavian low, linking central Europe (SW Germany, NE France, West Switzerland) with Catalonia (Fig. 3b). The pathway drawn by these back trajectories crossed the Pyrenees range at a region where it reaches altitudes of 3000 - 3500 m. Therefore, the Pyrenees could act as a barrier for the transport. In order to study this particular fact, a more refined analysis was performed by using the MM5 mesoscale model. The simulation started on the 15th May at 00 UTC, and continued for 3 days. Atmospheric variables were obtained every hour. The comparison between the trajectories obtained from the MM5 smallest domain results and the hourly pollen distribution in the study stations in Catalonia (Fig. 5) allowed a more refined interpretation of the pollen arrival at the area. During the 15th May there was a heterogeneous air mass flux, and only one station (Girona) received northern winds (Fig. 4a). At that moment, the pollen was scarcely present in the monitoring stations. The air flux started to be more organized on the 16th May. At 00 UTC, 06 UTC and 12 UTC all the stations showed an entrance of northern air masses (Fig. 4b, c, d). Simultaneously, the hourly distribution showed a first appearance of pollens at all stations (Fig. 5d, e, f). The situation changed between 12 and 18 UTC (Fig. 4e), when only Girona received northern air masses, the other stations being disconnected from the northern flux (Fig, 4 e). However, on the 17th May at 00 UTC (Fig. 4f), the air flux was again from the northeast, reaching a homogeneous orientation in all stations on the 17th at 06 UTC (Fig 4g). This synoptic situation produced the maximum amount of pollen in all the stations as can be seen from the hourly records (see Fig 5g-h). Afterward, the situation changed towards an easterly wind pattern from the Mediterranean Sea, which was clearly established at 18 UTC (Fig 4 i). Pollens were still found in the atmosphere, although quickly decreasing (Fig. 5).

The mesoscale model MM5 takes into account the local scales of the atmosphere besides the regional features and the regional patterns of wind movement**.** It must be noticed that the northern European fluxes simulated with MM5 showed a particular characteristic that could not be distinguished with Hysplit. For the event on the 17th May 2004, Hysplit modelled the trajectories straight back from the north (Fig 3b), while the MM5 model added detail by showing a consistent flow through the easternmost Pyrenean extreme at the Alberes region (500m asl), an easier pass than the 3000-3500 m asl altitudes of the central Pyrenees. Therefore, these two back trajectory models contained complementary information: long-range transport, or the provenance source, was best inferred with Hysplit which suggested probable source forests in the Jura **(France–Switzerland border), the Vosges (NE France), and the Schwarzwald (SW**

Germany). On the other hand, MM5 added value by modelling the transport at the regional scale, being able to trace the path through the easternmost Alberes pass.

Source areas

The application of the receptor model to pollen data from the period 1997-2006 enabled to identify probable source regions of the *Fagus* pollen. In Fig. 6 it can be observed that the model suggests a broad provenance area between the north of Italy, Switzerland, northeastern France and southwestern Germany, a region extensively covered by beech forests. It must be noticed that the outstanding event on the 16-17 May 2004 was also back-traced to this region. Several studies have shown that the source-receptor methodologies are adequate tools for identifying long distant source areas (Charron et al. 1998).

Contribution to phylogeography and palaeopalynology

The results obtained in this study show that *Fagus* pollen can be occasionally transported very far away from the source forests. This fact may affect other disciplines, such as palaeopalynology and phylogeography. For example, Bradshaw (2004), among others, considered that *Fagus* pollen does not travel far from its source and that relative abundance of pollen is a relatively unbiased reflection of the abundance of trees in the surrounding forests. Our results, indicating long range transport, suggest that *Fagus* distribution maps elaborated from paleopalynological evidence could in some cases overepresent these local forests.

As for phylogeography, Magri et al. (2006) evaluated the genetic consequences of long-term survival of *Fagus* in refuge areas and the postglacial spread from palaeobotanical data (400 fossil pollen sites and 80 plant-macrofossil sites) and genetic data (450 and 600 modern populations analysed for chloroplasts and nuclear markers, respectively). In Angiosperms, chloroplasts markers are only maternally inherited (Liepelt et al. 2002), so we refer only to the results published by Magri et al. (2006) on the isozyme data (nuclear markers). These results established a geographical distribution of isozyme groups through the Pyrenees, in France and Catalonia that are better explained by episodes of long range transport of *Fagus* pollen as those shown in this paper. The problems traditionally faced in species delimitation and phylogeny reconstruction may be in part due to a combination of weak reproductive barriers and the large distances that can be covered by genetic information as a result of wind pollination (Schmidt-Lebuhn, 2007).

Conclusions

This study shows that beech pollen dispersal can cover thousand of kilometres. Hysplit back trajectories and the MM5 model were useful for describing the pollen transport and the two models provided complementary information. Long range transport and probable source areas in central Europe were best described with Hysplit back trajectories and its associated source-receptor model, while MM5 allowed for more detail at the local scale, being able to trace the flow path through the Pyrenean range.

The fact that Fagus pollen peaks appeared simultaneously in different stations across the Catalan geography indicated a broad scale phenomenon, dominating over the local influence. The application of a source receptor model showed that the area in Europe from north Italy to central Germany, rather than the Pyrenean region, was the most probable area of emission responsible of the pollen peaks collected in Catalonia. This region is covered by extensive beech forests. The detailed study of the event on the 17th May 2004, when the highest pollen levels in the 23 yr record were observed, showed that the provenance area was in the Vosges (NE France) or the Schwarzwald (SW Germany).

This long range transport can have consequences in the understanding of modern pollen genetic diversity and give some clues for future interpretations of fossil pollen diagrams. Also, because of the reported allergenecity of the *Fagus* pollen, the correct understanding of the pollen dispersal is an urgent demand of the health care system.

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IEFC Inventari Ecològic i Forestal de Catalunya, http://www.creaf.uab.es/iefc/

IFN2 Inventario Forestal Nacional, http://www.mma.es/portal/secciones/biodiversidad/inventarios/ifn

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Table 1. Geographical and climatic characteristics of the Catalan aerobiological stations.

Geographical characteristics			Climatic characteristics	
Main stations	Altitude (m)	Geographical coordinates	Mean Annual Temperature (ºC)	Annual Rainfall (mm)
Barcelona	93	41º24’N, 02º09’E	16.4	593
Bellaterra	245	41º33’N, 02º06’E	15.2	594
Girona	98	41º59’N, 02º50’E	15.0	740
Lleida	202	41º37’N, 00º38’E	15.1	385
Manresa	291	41º44’N, 01º30’E	13.6	619
Tarragona	44	41º07’N, 01º15’E	15.8	478

Table 2. *Fagus* pollen absolute peaks in Catalan stations for the period 1983-2007 and the corresponding back trajectories. Cour data is shown in italic.

Year	**Date**	**Locality**	**Peak concentration**	**Back trajectory**
1984	*w. 19 (07-13/05)*	*Seu d'Urgell*	*1,4 p/m^3*	N
1985	*w. 21 (20-26/05)*	*Barcelona*	*1,6 p/m^3*	several, NE included
1989	*w. 18 (01-07/05)*	*Girona*	*8,7 p/m^3*	N
		Tarragona	*6,5 p/m^3*	
	w. 20 (15-21/05)	*Barcelona*	*9,1 p/m^3*	several, N included
		Bellaterra	*1,0 p/m^3*	
1990	*w. 17 (23-29/04)*	*Barcelona*	*1,0 p/m^3*	N
		Bellaterra	*1,4 p/m^3*	
		Girona	*1,5 p/m^3*	
1991	*w. 21 (20-26/05)*	*Tarragona*	*1,8 p/m^3*	N
	w. 23 (03-09/06)	*Bellaterra*	*1,2 p/m^3*	N and NW
1992	*w. 18 (27/04-03/05)*	*Barcelona*	*2,5 p/m^3*	N and NW
		Bellaterra	*2,4 p/m^3*	
	w. 19 (04-10/05)	*Girona*	*6,9 p/m^3*	N and NW
	w. 20 (11-17/05)	*Lleida*	*2,3 p/m^3*	several, N included
1994	*w. 17 (16-22/04)*	*Girona*	*2,0 p/m^3*	several, N included
	27/04	Bellaterra	1,4 p/m^3	N
	03/05	Barcelona	1,4 p/m^3	W
1995	*w. 15 (10-16/04)*	*Lleida*	*4,4 p/m^3*	N
		Bellaterra	*1,8 p/m^3*	
	13/04	Bellaterra	4,9 p/m^3	NE
	w. 17 (24-30/04)	*Girona*	*3,7 p/m^3*	several
	02/05	Barcelona	4,2 p/m^3	N
	w. 19 (08-14/05)	*Tarragona*	*1,1 p/m^3*	NNW
	14/05	Girona	1,4 p/m^3	N
1996	*W. 16 (14-20/04)*	*Bellaterra*	*1,6 p/m^3*	several, N included
1997	04/04	Girona	9,8 p/m^3	N
	16/04	Lleida	4,9 p/m^3	N
	21/04	Barcelona	4,9 p/m^3	NE
		Bellaterra	5,6 p/m^3	
		Tarragona	2,1 p/m^3	
1998	15/05	Girona	2,1 p/m^3	N
		Tarragona	1,4 p/m^3	
1999	22/04	Bellaterra	2,8 p/m^3	W
	03/05	Manresa	7,0 p/m^3	E to N
	12/05	Lleida	4,2 p/m^3	SW
		Girona	18,9 p/m^3	
	13/05	Barcelona	8,4 p/m^3	SW
	14/05	Tarragona	2,8 p/m^3	W
2000	07/05	Girona	2,1 p/m^3	E
2001	29/05	Girona	2,8 p/m^3	NW
		Bellaterra	1,4 p/m^3	
		Barcelona	1,4 p/m^3	
	31/05	Lleida	1,4 p/m^3	N and NW
2002	21/04	Barcelona	4,2 p/m^3	NE
		Bellaterra	3,5 p/m^3	
	25/04	Girona	18,9 p/m^3	N
	26/04	Lleida	2,8 p/m^3	NW
2003	13/05	Girona	1,4 p/m^3	W
2004	17/05	Lleida	91,0 p/m^3	NE
		Bellaterra	38,5 p/m^3	
		Girona	37,8 p/m^3	
		Barcelona	37,1 p/m^3	
		Manresa	29,4 p/m^3	
		Tarragona	26,6 p/m^3	

2005	19/04	Manresa	2,8 p/m³	W
	09/06	Tarragona	1,4 p/m³	N
2006	25/04	Manresa	9,1 p/m³	N (local)
	26/04	Barcelona	7,0 p/m³	NW
		Bellaterra	2,8 p/m³	
	29/04	Girona	32,9 p/m³	NW
		Tarragona	12,6 p/m³	
		Lleida	6,3 p/m³	
2007	23/04	Lleida	2,8 p/m³	E
	04/05	Bellaterra	3,5 p/m³	NW
		Girona	5,6 p/m³	NW

Table 3. Annual **Pollen** Indexes (**API**=sum of daily counts) registered for *Fagus* pollen in Catalonia for the period 1983-2007. Cour (italic), Hirst (normal) and absolute **API** maximum data (bold) are shown.

Year	**Barcelona**	**Bellaterra**	**Girona**	**Lleida**	**Manresa**	**Tarragona**
1983	*10,3*					
1984	*1,6*					
1985	*27,5*					
1988	*1,3*	*2,8*				
1989	*78,1*	*14,1*	*108,9*			*65,8*
1990	*9,2*	*18,0*	*22,3*			*4,0*
1991	*8,6*	*22,0*	*12,2*			*14,7*
1992	*43,7*	*45,3*	*101,0*	*49,8*		*6,6*
1993	*2,6*	*0,0*	*2,4*	*4,3*		*0,6*
1994	2,8	7,7	*40,1*	*10,0*		*0,5*
1995	16,1	25,9	*41,2*	*58,7*		*14,8*
1996	1,4	0,7	3,5	0,0	0,0	0,0
1997	21,7	20,3	63,7	18,2	7,7	7,0
1998	1,4	5,6	9,1	2,1	0,0	1,4
1999	16,1	18,2	130,2	16,1	21	10,5
2000	1,4	1,4	4,2	0,0	0,0	0,0
2001	2,1	2,8	7,0	2,1	0,0	0,7
2002	21,0	21,0	142,8	11,2	16,1	2,8
2003	1,4	0,7	5,6	0,0	0,0	1,4
2004	**127,4**	**126,7**	**338,1**	**169,4**	**130,9**	**92,4**
2005	2,8	2,8	16,8	0,7	2,8	4,9
2006	**19,6**	18,2	109,2	28,0	55,3	39,2
2007	2,8	9,8	31,5	1,4	8,4	28,0
Absolute Max	**127,4**	**126,7**	**338,1**	**169,4**	**130,9**	**92,4**
Year	**2004**	**2004**	**2004**	**2004**	**2004**	**2004**
2ond Max	**19,6**	**25,9**	**142,8**	**28,0**	**55,3**	**39,2**
Year	**2006**	**1995**	**2002**	**2006**	**2006**	**2006**

Table 4. Dates for *Fagus* pollen peaks in 2004 and 2006. The stations where the peak was observed and the provenance of the air mass according to Hysplit back trajectories are also shown. The sampling stations are B=Barcelona, Be= Bellaterra, G= Girona, L=Lleida, M= Manresa, T=Tarragona. The provenances are AF= African, AT= Atlantic, EU= European, ME=Mediterranean, PE= Iberian Peninsular.

2004			**2006**		
Date	**Sampling Stations**	**Trajectory Origin**	**Date**	**Sampling Stations**	**Trajectory Origin**
23-apr	G	EU	21-apr	T	AT
25-apr	BBeGM	EU	22-apr	M	AF
30-apr	M	EU	24-apr	LM	ME
04-may	GM	EU	25-apr	BLM	ME
05-may	Be	AT or EU	26-apr	BBeGT	EU
06-may	Be	EU	27-apr	LM	EU
07-may	T	EU	28-apr	BBeGT	EU
09-may	G	AT	29-apr	GLMT	EU
12-may	BeGMT	EU	01-may	G	EU
13-may	GLT	EU	02-may	L	ME
14-may	LMT	EU	03-may	BeMT	ME
15-may	B	EU	04-may	M	ME
16-may	BBeGM	EU	05-may	BT	ME
17-may	BBeGLMT	EU	06-may	GL	EU
19-may	B	EU	07-may	BeM	ME
20-may	M	EU	08-may	T	AT
22-may	BBeG	PE or EU	09-may	GM	AT
24-may	BGMT	EU	10-may	BeM	PE
26-may	BeG	EU	11-may	G	PE
27-may	BBeGM	EU	13-may	L	ME
29-may	BeG	EU	14-may	B	ME
30-may	M	PE	15-may	GMT	ME
31-may	G	EU	16-may	Be	ME
01-jun	G	EU	17-may	BeGT	PE
03-jun	T	EU	19-may	Be	AT
04-jun	BM	EU	20-may	M	AT
06-jun	M	EU	21-may	GT	PE
07-jun	BeG	EU	22-may	BT	PE
			26-may	T	EU
			27-may	G	EU
			30-may	T	EU
			06-jun	T	EU

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Table 5. Contingency tables for testing the null hypothesis of independence of *Fagus* pollen peaks and the entrance of European air masses (inferred from Hysplit back trajectories) at the monitoring sites of Girona and Barcelona for the two years of highest *Fagus* pollen in the 1983-2007 record.

		European	Non European	Total
Girona 2004	Pollen peak	14	2	16
	No pollen peak	30	26	56
	Total	44	28	72
			X^2=6.03; p=0.014	
Barcelona 2004	Pollen peak	9	0	9
	No pollen peak	35	28	63
	Total	44	28	72
			X^2=6.55; p=0.0105	
Girona 2006	Pollen peak	6	5	11
	No pollen peak	14	47	61
	Total	20	52	72
			X^2=4.64; p=0.031	
Barcelona 2006	Pollen peak	3	3	6
	No pollen peak	17	49	66
	Total	20	52	72
			X^2=2.03; p=0.155	

Figure captions

Fig 1. a) *Fagus* distribution map in Europe, from Magri et al. (2006), and b) Catalonia showing the MM5-model domain, sampling sites and inventory plots with *Fagus* (blue circles). Catalan beech distribution has been composed from inventories IEFC and IFN2 (see references).

Fig. 2. Mean daily airborne *Fagus* pollen concentrations in the Catalan stations from 20 April to 30 May in: (a) 2004 and (b) 2006.

Fig. 3. a) Sea level pressure analysis at 00 UTC on 16 May 2004, and b) Hysplit back trajectories on 17 May 2004 at all the studied stations in Catalonia. Hysplit isentropic 96-h back-trajectories at 60-min time steps at 1500 m above sea level (asl), starting at 12 h UTC from the coordinates of each monitoring site. Available at http://www.arl.noaa.gov/ready/hysplit4.html (Draxler and Rolph, 2003)

Fig. 4. Back trajectories calculated with the MM5 model simulation at the Catalan stations (http://www.mmm.ucar.edu/mm5/mm5-home.html). Blue dots indicate inventory sites where *Fagus* is present (data from the IEFC and IFN2).

Fig 5. Mean hourly pollen concentrations (in pollen grains/m^3) at the Catalan stations from the 15 May at 00 UTC to the 18 May at 23 UTC 2004. Letters in the abscise axis refer to graphics in Fig. 4 to illustrate the correspondence of pollen abundance and the transport modelled with MM5.

Fig. 6. Areas contributing to *Fagus* pollen concentrations, inferred from a source-receptor model applied to spring pollen counts (1 April to 30 June) at the Catalan stations for the period 1997-2007. See text for more details.