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Ambrosia L. in Catalonia (NE Spain): expansion and aerobiology of a new bioinvader

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Abstract This paper aims to determine the stage of the naturalization of ragweed (*Ambrosia* L.) in Catalonia, north-east Spain, and to analyze the airborne pollen pattern and provenance, in order to contribute to a better management of it and prevent the expansion of a possible new bioinvader that can also become a health problem due to its highly allergenic pollen. Biogeographical sampling consisted on the monitoring of *Ambrosia* populations through the territory over a 2-year period (2010–2011). Aerobiological sampling was based on the analysis of pollen records at eight aerobiological sampling stations, during the period 1994–2010. Pollen provenance sampling was examined using backward atmospheric air masses trajectories and synoptic maps, as well as through the application of a source-receptor model. *Ambrosia* colonies are expanding throughout the territory at a mean growing rate of 324% for the sampled territory. The Annual Pollen Indices appear to be clearly influenced by the pollen concentrations in the peak dates, and these are linked to long-range transport of pollen from regions where *Ambrosia* is widely widespread, such as eastern France, northern Italy and Hungary and Serbia. The episodes of pollen transport are increasing in number. Although airborne *Ambrosia* pollen type is not showing any clear increasing trend for the period under study, local populations of the plant could be having an influence on the pollen records, since the genus is clearly expanding in the territory at considerably high spread rates. *Ambrosia* populations have to be surveyed both for public health reasons and as a new bioinvader.

Keywords Airborne pollen · Allergy · *Ambrosia* · Invasive weed · Long-range transport · Ragweed

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1 Introduction

The study and comprehension of the dispersal of bioaerosols are becoming increasingly important due to its implications in terms of biogeography and public health. Traditionally, the dispersal of bioaerosols had

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been studied taking only into account short distances from the sources, but the recent evidence of pollen and spore transport over much greater distances (Belmonte et al. 2000, 2008; Siljamo et al. 2007) urges aerobiologists to account higher scales in the atmospheric transport modeling. Anemophilous pollen dispersal over great distances gives causes for concern because of its potential to affect the human health and to the expansion of the biogeographical ranges of different plants, particularly bioinvaders (Voltolini et al. 2000; Asero 2002).

The pollen dispersal modeling constitutes an important tool for the study of invasion ecology, which has received considerable attention in the recent years (Laaidi et al. 2003; Belmonte and Vilà 2004; Taramarcaz et al. 2005). In this sense, the prediction of which species will become bioinvaders (Křivánek and Pyšek 2006) or the design of appropriate management and control strategies for certain species are currently some of the most significant fields of study. Early detection of the introduction of an invasive harmful taxon can be decisive to the prevention of its expansion—and therefore, its impacts—making the difference between employing offensive strategies against the species (eradication) or defensive ones (Rejmánek et al. 2005).

Biological invasions can have important aerobiological consequences, as sometimes they entail the dispersal of new aeroallergens (Asero 2002; Confalonieri et al. 2007). In this study, we have concentrated in one paradigmatic case of this phenomenon: the dispersal of ragweed (*Ambrosia* L.) pollen type. *Ambrosia* is a genus of plants of the Asteraceae family widely studied in aerobiology due to its highly allergenic pollen. It is abundantly distributed in North America and is becoming frequent in continental Europe, where it has been expanding in the recent years and is considered a bioinvader (Mabberley 1987; Dana et al. 2003), due to its enormous spread potential and its huge pollen production.

There are twenty-four *Ambrosia* species throughout the world (Mabberley 1987), six of them in Europe and only one—*Ambrosia maritima*—being autochthonous. The first temporary colonization of *Ambrosia* in Europe was reported from Brandenburg, Germany, in 1863 (Hegi 1908), although the distribution of *Ambrosia* in Europe did not start until the First World War, when seeds were transferred from America by purple clover seed shipments and imports of horse forage and grain birdseed (Comtois 1998). Since then, these weeds have encountered ideal conditions to develop and spread all along the continent through different pathways. *Ambrosia* can easily spread disseminating its seeds through watercourses, as it has been reported in many countries such as Slovenia or Germany (Brandes and Nitzsche 2007). Wind still remains as one of the most important pathways for the introduction of seeds, especially in countries bordering heavily infested areas (Jäger and Litschauer 1998). Other introduction pathways include trains, highways, railways and the exchange and movement of soils, gravels, building materials or harvesters between different areas (Buttenschøn et al. 2009).

Up until the 1970s, *Ambrosia* weeds were just one among the several noxious weeds in agricultural fields, but nowadays, the spreading rate of ragweed species is much higher. Noticeable increasing trends of both amounts and daily concentrations of *Ambrosia* pollen have been detected in most part of the European aerobiological stations in regions such as Burgundy, France (Laaidi and Laaidi 1999), Poland and Croatia (Cvitanovic et al. 2004), central-northern Italy (Cecchi et al. 2007) or the Ticina canton, Switzerland (Peeters 2000). This may be explained taking into account several considerations. First of all, set-aside practises in agricultural fields, promoted by the European Common Agricultural Policies (ECAP) and the abandon of fields provide an ideal habitat for *Ambrosia* species (Déchamp and Riotte-Flandrois 1995), since they prefer fertile and freshly moved grounds. Secondly, with globalization, the increasing transportation of goods and the rising of communication nets (such as highways, railways or airports) benefit the spread of *Ambrosia* along the continent. In third place, the mounting number of construction sites and waste places provide new habitats for *Ambrosia* species. And finally, since climate is an important factor controlling the persistence of ragweed, global warming may be exacerbating the dispersal of *Ambrosia* in Europe (Wayne et al. 2002).

Highly infested regions in Europe include the Lyon region in the French Rhone Valley (Laaidi and Laaidi 1999; Laaidi et al. 2003), the Italian Po Valley (D'Amato et al. 1998; Mandrioli et al. 1998), some former Yugoslavian States, such as Croatia (Peternel et al. 2005) or Serbia (Juhász et al. 2004; Šikoparija et al. 2006), and Hungary (Jarai-Komlodi and Juhász 1993; Juhász et al. 2004), where *Ambrosia*-induced allergies are very important (Rybnícek and Jäger 2001). It is important to note that *Ambrosia* is one of the major allergens in North America, where approximately 10% of the population is allergic to it (Rogers et al. 1996). Moreover, it can be considered the main aeroallergenic plant in Hungary (Juhász 1995), where at least 60% of the pollen-sensitivity is caused by *Ambrosia* (Makra et al. 2005). On the other hand, up to 15% of the Lyon region population suffers from allergies (hay fever, asthma…) to *Ambrosia* pollen (Taramarcaz et al. 2005).

The distribution of *Ambrosia* species in Spain has never been studied as a whole. Although many *Ambrosia* populations appear to be expanding over the territory, Spain has never participated in the European networks for its control. In this study, we have focused on the region of Catalonia, in north-east Spain. The Aerobiological Network of Catalonia (Xarxa Aerobiològica de Catalunya, XAC) is monitoring since 1983, the atmospheric pollen concentrations, in order to make a follow-up of the possible risk of respiratory allergies and the distribution of certain species throughout the region. One of the taxa considered in the analyses of airborne samples is *Ambrosia* pollen type (which includes *Xanthium* pollen due to the difficulties in discriminating them), being the only regional network in Spain that takes into account this pollen type at present. From 1983 to 1993, the airborne sampling method followed in Catalonia was Cour (1974) while since 1994, the sampling and analyses are done following the methods accorded as standard (Galán et al. 2007) in the Spanish Aerobiological Network (Red Española de Aerobiología, REA). The peak concentrations of *Ambrosia* pollen observed in 1996 at most of the Catalan aerobiological stations (Belmonte et al. 2000), caused by a long-range transport event, urged Catalan aerobiologists to closely watch the *Ambrosia* pollen flows, which might be playing a role in the generation of an allergy risk to the population, as well as contributing to the expansion of the genus in Spain. Furthermore, the existence of cross-reactivity (Yman 1982) between the pollen of several Asteraceae genera (*Xanthium*, *Helianthus*, *Artemisia*, *Taraxacum* and others), most of which are abundant in the Spanish flora, may enhance the risk of allergies caused by *Ambrosia*.

The aim of this work is to analyze the distribution pattern of the *Ambrosia* species in Catalonia, in order to determine the stage of their naturalization in the region. This is the first paper to document and collect all the field observations of *Ambrosia* in Spain. Thereby, we will focus on the role of pollen in the expansion of the species and its implications in terms of biogeography. The sampling comprised the following: (a) the monitoring of seven *Ambrosia* populations over a 2-year period, in order to determine whether an increase in the size of the populations is taking place in the region, and (b) the following of the pollen records of the Aerobiological Network of Catalonia (XAC) with view to the implications in terms of public health. This study is a contribution to the control of the outcome of *Ambrosia* in Catalonia, with the purpose of preventing possible allergy risk situations to the population, as well as the expansion of a possible new bioinvader.

2 Materials and methods

2.1 Biogeographical data

Due to the fact that *Ambrosia* sp. is not a very widespread genus in Catalonia, and moreover, the information about it is mostly fragmentary and very limited, the first step required for the present study was to document the distribution of the species in the territory. Although we have focused mainly in Catalonia, we also highlighted data about *Ambrosia* populations in other regions of Spain, in order to contribute to a better understanding of the distribution patterns of the genus in the Iberian Peninsula.

A bibliographical research was made in order to collect all the citations of the species in Spain. This comprised several scientific publications, as well as all the references cited in the records of the National Botanic Conservatories of Spain. Therefore, several databases were checked. These included the Euro + Med PlantBase (Euro + Med 2011), the Anthos Project Database, from the Royal Botanic Gardens of Madrid (Anthos 2011), and the Biodiversity of Catalonia DataBank, from the University of Barcelona (Font 2011).

Several populations cited in the literature were checked and monitored in the field. In order to check the progress of the populations and as no published information about their size was available, a measurement in situ was made in seven of the populations. The chosen populations were located in the province of

Barcelona, in the municipalities of El Prat del Llobregat, Mollet del Vallès and Montcada i Reixac. All populations corresponded to *Ambrosia coronopifolia*, the most widespread species in the region. An early measurement was made on the first week of July 2010, and a second one was completed 1 year later. These dates were chosen because they correspond to the period of the year—out of the pollination time—in which *Ambrosia* is at its maximum growth rate (Déchamp 1995). The monitoring over a 2-year period was arranged to check whether an increase on the size of the populations can be inferred for Catalonia.

2.2 Aerobiological data

2.2.1 Pollen sampling methods and stations

Ambrosia pollen type has been monitored on a daily basis by the Aerobiological Network of Catalonia, over a 17-year period (1994–2010). Figure 1 shows the locations of the eight sampling sites studied in Catalonia: Barcelona, Bellaterra, Girona, Lleida, Manresa, Tarragona, Roquetes-Tortosa and Vielha.

The pollen sampling was performed using the Hirst method (Hirst 1952), the standard method approved by the International Association for Aerobiology, and pollen counts were obtained following the norms established by the Spanish Aerobiology Network (Red Española de Aerobiología, REA; Galán et al. 2007). The analyses were performed by the Aerobiological Network of Catalonia, at the Palynological Laboratory of the Universitat Autònoma de Barcelona (UAB).

Although some authors note that *A. coronopifolia* pollen grains have a slightly greater diameter (Bassett and Terasmae 1962; Kapp 1969) or that *Ambrosia tenuifolia* pollen grains have larger spines (Solomon and Durham 1967) than the pollen from other species, all of them are indistinguishable to most pollen counting professionals due to the strong intraspecific variability in pollen sizes. Therefore, the pollen counting has been performed at the genus level, the lowest taxonomical rank possible in this case.

2.2.2 Study of air mass trajectories

The provenance of the air masses in the dates in which *Ambrosia* pollen concentrations showed peaks were examined, in order to analyze the role of long-distance transport in the expansion of the pollen of the species. This was made using backward atmospheric trajectories. Isentropic 120-h back-trajectories at 500, 1,000 and 1,500 m a.s.l., starting at 12UTC from the geographical coordinates of each monitoring site, 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 and Rolph 2003)] from the gridded meteorological fields of the FNL and GDAS archive data. According to the area crossed by the backward trajectories, the trajectory origin was classified following the cardinal directions (detailed in Table 3).

The interpretation of the backward trajectories was complemented with meteorological synoptic maps from the UK Meteorological Service [available at http://www.weathercharts.org/ukmo-analysis/], which were used to simulate some specific meteorological situations with exceptionally high pollen levels.

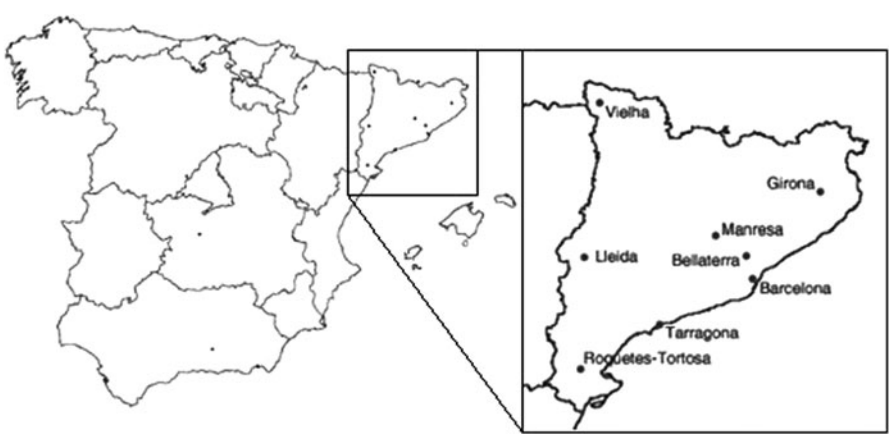

Fig. 1 Locations of the stations of the aerobiological network of Catalonia (Xarxa Aerobiològica de Catalunya, XAC)

2.2.3 *Source-receptor model*

A statistical approach combining pollen concentration data at the monitoring stations with the backward trajectories ending at these locations was applied to infer the source areas for the *Ambrosia* pollen reaching Catalonia in the study period. Such source-receptor methodologies establish relationships between a receptor point and the probable source areas by associating each value of pollen abundance with its corresponding backward trajectory.

In this study, two daily backward trajectories (at 00 and 12 UTC) were considered, at 500 and 1,500 m during *Ambrosia* flowering period (25 June to 10 October) for a 13-year period from 1997 to 2009. A grid, in this case composed of 2601 cells of 1° × 1° latitude and longitude, was then superimposed on the integration region of the trajectories in order to map the contributing areas.

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, was applied:

$$\log C_{ij} = \frac{\sum_l n_{ijl} \log C_l}{\sum_l n} \quad (1)$$

where C_{ij} is the pollen 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. To minimize the uncertainty of the trajectories, a smoothing was applied and the value of each cell was replaced by the average between the cell and the eight neighboring cells. A final filter excluded cells with less than five end points. The abundance field map obtained in this manner reflects the contribution of each cell to the pollen abundance at the receptor point.

Average relative horizontal position errors for three-dimensional trajectories were estimated to be less than 20% for travel times longer than 24 h in the free troposphere. Upper bounds for average absolute horizontal and vertical errors after 120 h travel time were 400 km and 1,300 m, respectively (Stohl and Seibert 1997). Due to turbulent mixing, there is a loss of reliability in the trajectories computed in the boundary layer. Therefore, the height of 1,500 m, corresponding to 850 hPa standard pressure level, was selected as most representative for transport in the lower troposphere. This layer is typically sensitive to cyclonic wave features and is the approximate boundary between the surface wind regime and the free troposphere.

3 Results and discussion

3.1 *Ambrosia* distribution in Spain and Catalonia

In Spain, there are five *Ambrosia* species, only one of them considered autochthonous (Font 2011). They are not very widespread in the territory, but some populations appear to be expanding, having encountered suitable conditions for a rapid spread. The first Iberian citations of the genus *Ambrosia* date back to the XIXth century and correspond to *A. maritima*, the only native species found in the Peninsula (Pérez 1887). Nevertheless, focusing on the alien species, such as *A. coronopifolia* or *Ambrosia artemisiifolia*, the first references date from the 1960s, when a sample of *A. coronopifolia* was found in Montcada i Reixac, close to Barcelona (Bolòs and Bolòs 1961). Other early citations of *Ambrosia* in the Iberian Peninsula include some colonies of *A. artemisiifolia* near Santander, northern Spain (Laínz and Loriente 1983). Since then, the citations of *Ambrosia* in the area have increased considerably, as shown in Table 4 and Fig. 2.

The distribution of *Ambrosia* species in Spain (Fig. 2) might be explained paying attention to the harbors as the main entry gates of seeds to the peninsula. In fact, the major ragweed colonies found in Spain and Portugal are closely linked with some of the most important harbors, such as Barcelona, Bilbao, Lisbon, Porto, Santander or Valencia. On the other hand, dispersal of seeds through the wind does not seem to be the major cause of arriving to the Iberian Peninsula, since the Pyrenees act as a barrier preventing the entrance of ragweed in the country. Nevertheless, the outcome of *Ambrosia* populations in Spain could be greatly favoured by long-range transportation of pollen, caused by unusual conditions of atmospheric circulation, from regions where the species is abundant as the Lyon region in France (Déchamp and Cour 1987; Belmonte et al. 2000). Such processes will be discussed later on.

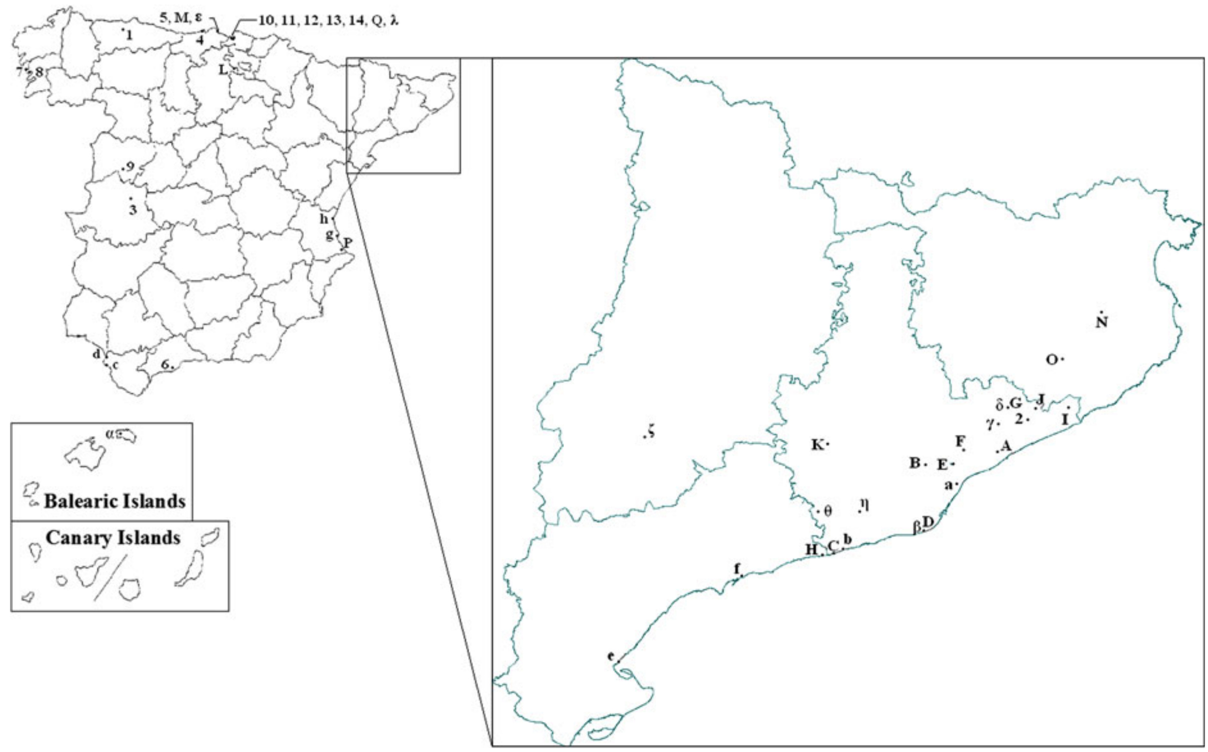

Fig. 2 *Ambrosia sp.* locations in Spain, with special focus on Catalonia as the most infested region in the country. *Numbers* correspond to *A. artemisiifolia*, *capital letters* correspond to *A. coronopifolia*, *lower-case letters* correspond to *A. maritima* and *Greek letters* correspond to *A. tenuifolia*. Precise location of the *Ambrosia* populations and bibliographical references are gathered in Table 4, in Appendix S1

Sea Ragweed (*A. maritima*) can be found in some maritime locations around the Mediterranean Coast and it was the only *Ambrosia* species to be found in the Balearic Islands until the recent discovery of a colony of *A. tenuifolia* in Minorca (Fraga and García 2004). Common Ragweed (*A. artemisiifolia*) seemed to be only present in the Basque Country, the Cantabric coasts and Galice, but according to some recent studies, it appears to be extending to central Spain (Amor et al. 2006). Perennial ragweed (*A. coronopifolia*) is naturalized in many littoral and pre-littoral areas of Valencia and Catalonia (Casasayas 1989), as well as in the Basque Country and some locations near Santander. Finally, *A. tenuifolia* is well established in some locations along the Catalan coast and *A. trifida*, the less common species, can be mainly found in the Basque Country and is the only species not to be found in Catalonia (Anthos 2011).

Catalonia seems to be the region of Spain where *Ambrosia* is more abundant. This may be due to the closeness to France where the plant is not rare and to the climatic conditions favorable to the expansion of the species. The temperature requirement during the flowering time at the end of the summer is a limiting factor in the success of the naturalization of the species (Déchamp 1992), and it seems that these conditions are attained in certain areas of Catalonia. Allard (1943) predicted that the Rhone Valley, in France, would be a potentially good area for the naturalization of *A. artemisiifolia*. In line with these predictions, some littoral and pre-littoral disturbed areas in Catalonia seem to be suitable candidates for the development of *Ambrosia* in the territory. These include the banks of rivers such as the Besòs (Devis 2009) or the Tordera (Boada et al. 2009), where *Ambrosia* is starting to spread through different pathways (specially the river flow), or some of the sand dunes along Barcelona's shore (Del Hoyo and González 2001). For the moment, the expansion of *Ambrosia* in Catalonia mainly concerns *A. coronopifolia*, but since this species has the same ecology and habitat preferences than *A. artemisiifolia*, the data that we elucidate can be inferred for the whole genus. Regarding the allergenic potential of each species, they all shed large quantities of airborne pollen with cross-reacting allergens (Wodehouse 1971; Ghosh et al. 1994). However, the more localized occurrence of *A. coronopifolia* and the smaller size of the plants lessen its importance as a cause of allergenic diseases, when compared to other species such as *A. artemisiifolia* (Bassett and Crompton 1975).

The results of the monitoring of the *Ambrosia* populations in Catalonia over a 2-year period (Table 1) showed that *Ambrosia* populations are generally increasing in size. Five colonies, out of the seven checked, appeared to be expanding over the territory, with a mean growing rate of 324% for the sampled territory in Catalonia. The percentage of growth in the expanding populations ranged between 646% (see D.1., El Prat del Llobregat, in Table 1) and 117% (see F.3., Mollet del Vallès, in Table 1). In 1 year and considering the whole area studied, the *Ambrosia*-invaded surface increased in 3,025 m^2. The colony showing the highest rate of increase in size, D.1. in El Prat del Llobregat, happens to be located in the surroundings of the new terminal (T1) of the Barcelona airport. Although it is rarely cited in literature, airports could be playing an important role on the spread of *Ambrosia* and other noxious weeds. Apparently, the number of colonies of *A. coronopifolia* in the area has increased considerably in the recent years, following the creation of the Terminal. In the case of the other colonies studied, it is important to highlight the direction in which the expansion is taking place. *Ambrosia* populations in Montcada i Reixac (see populations E.1. and E.2. in Table 1) were also growing at high rates and appeared to be expanding in the direction of the Besòs River, whereas in Mollet del Vallès, the outcome of *Ambrosia* (population F.3. in Table 1) followed the path of the railway train. This is in clear accordance with the studies claiming that human activities play an important role in the spread of ragweed species (Déchamp and Riotte-Flandrois 1995; Comtois 1998; Makra et al. 2005).

The spreading rates found for the populations checked seem to indicate that *Ambrosia* sp. has found

Table 1 Results of the *Ambrosia* populations monitoring in Catalonia over a 2-year period [2010–2011]

Map code	Locality	Population	UTM coordinates	Surface 2010 (m^2)	Surface 2011 (m^2)	Growth rate (%)	Observations
D	El Prat del Llobregat	D.1.	*x*: 422661.3 *y*: 4570467.5	180	370	206	Disturbed sands in the shore, some of them under regime of conservation (in the Delta del Llobregat Natural Park). Close to the new terminal of the Barcelona Airport [T1]
		D.2.	*x*: 423096.3 *y*: 4570667.5	500	3,230	646	
E	Montcada i Reixac	E.1.	*x*: 432493.3 *y*: 4592588.3	125	220	176	Ruderal lands with high anthropic pressure, on the Besòs riverbanks. The original population measured in 2010 had been divided in three sub-populations by 2011, following the retracement of a path. The freshly removed grounds provided an ideal habitat for the species. The outcome of *Ambrosia* is taking place in the direction of the river flow
		E.2.	*x*: 432535.8 *y*: 4592813.8	50	115	230	
F	Mollet del Vallès	F.1.	*x*: 435025.3 *y*: 4598544.3	100	0	−100	Great anthropic pressure. Close to the railway line between Barcelona and Montmeló. In 2011, one of the populations [F.1.] had been pulled up by a local farmer. Populations F.2. looks as if being displaced by *Chamaemelum* sp.
		F.2.	*x*: 435012.3 *y*: 4598486.3	45	30	−30	
		F.3.	*x*: 435093.8 *y*: 4598866.3	350	410	117	
Total for Catalonia				1,350	4,375	324	

in Catalonia an ideal habitat for its expansion. Freshly removed grounds (populations E.1. and E.2.) provide a particularly adequate habitat to the outcome of the species. Climate change might also be playing a role in the expansion of the genus, since the distribution of the taxon is favoured by a temperature increase and enriched CO_2 atmospheres (Wayne et al. 2002). No management strategies are currently taking place in Catalonia. The only documented measure for the control of *Ambrosia* in the region took place in El Prat del Llobregat in March 2009 (De Roa et al. 2009). A thinning of the vegetation cover of two ruderal bioinvaders, one of which was *A. coronopifolia*, was carried out to improve the nesting habitat of an emblematic species of the Delta del Llobregat Natural Park, the Kentish Plover (*Charadrins alexandrinus*). Nevertheless, it is important to point out that this measure was not focused on the eradication of the invasive species, but on the general decrease in the vegetation cover. It is also to be remarked that no alteration signs related to the 2009 thinning in the *Ambrosia* populations checked (D.1. and D.2.) were identified during the sampling period. The location of these populations may suppose a serious menace to public health, since they are located near one of the most popular beaches of the Delta del Llobregat Natural Park and the pollination occurs by the end of August, when the beaches are densely crowded.

3.2 Annual year pollen index tendencies

The annual pollen index (API, sum of the mean daily concentrations along the year) measured at the Catalan aerobiological stations considered individually in the period 1994–2010 (Table 2) ranged between 0 pollen grains (in Manresa and Tarragona, year 2000, Girona, year 2001, and Vielha, years 2004 and 2005) and 64 pollen grains (in Girona, year 1996). When considered all the sampling stations as a group (Table 2 and Fig. 3), the mean API ranged between 2 (year 2001) and 38 pollen grains (year 1996).

The APIs for *Ambrosia* showed a decreasing trend during the study period in four out of the eight sampling points. This did not seem to be in concordance with the noticeable increasing trends of the concentrations of *Ambrosia* pollen type in most of the European aerobiological stations. As a matter of fact, even if the tendencies showed a decreasing trend, these were mainly irregular and depend also on the

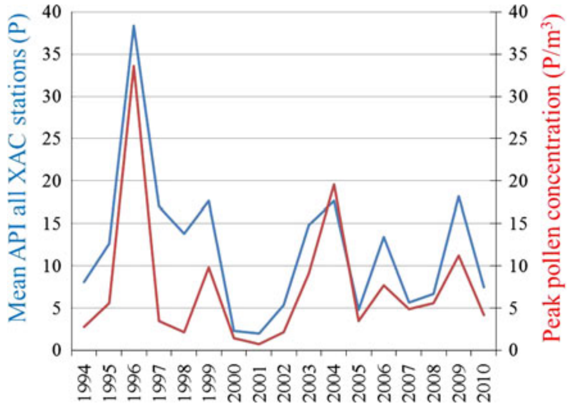

Fig. 3 Comparison between the mean annual pollen index (API) of all XAC stations and the absolute peak pollen recorded each year

temporary scale considered. From 1989 to 1995, the *Ambrosia* pollen levels detected in Catalonia were insignificant, but from 1996 onwards, the pollen counts of *Ambrosia* became more constant. Moreover, the number of long-range transport episodes of this pollen seemed to be increasing in the last years. This can be seen in Table 3. Global warming could be playing a role in this trend—as it does in the dispersal of the genus—since temperature and CO_2 increase the number of floral spikes per plant and therefore, pollen production (Ziska and Caulfield 2000). Also, the increasing number of areas infested by *Ambrosia* in Europe could be favoring a major number of long-range transport episodes of this pollen type.

In any case, the API tendencies for Catalonia appeared to be clearly influenced by the peak concentrations, which were often linked to long-range transport pollen intrusions. Figure 3 shows the relationship between the API and the peak concentrations for the whole of the Catalan aerobiological stations. In this sense, the fact that a big proportion of the API came from the peak dates reinforces the theory that long-distance transport plays a crucial role in the *Ambrosia* pollen type records in Catalonia. The proportion of the API coming from a peak date varied from 9% (Girona, August 14, 1997) to 60% (Tarragona, September 7, 2004), with a rate of 32% for all the stations during the period under study. For example, 60% of the *Ambrosia* pollen recorded in 2004 in Girona was collected on a single day (7 September). Moreover, 79% of the *Ambrosia* API for 2006 in Tarragona was recorded in only 2 days (6 and 9 September).

The API of *Ambrosia* pollen measured at a specific station can be considered a first estimate of how much of

Table 2 Annual pollen indices (API = sum of daily concentrations) registered for *Ambrosia* pollen type in Catalonia for the period 1994–2010

Year	Bar	Bel	Gir	Lle	Man	Tar	Vie	Roq	Mean
1994	4.9	11.2							8.1
1995	7.0	18.2							12.6
1996	53.9	44.8	64.4	14.7	36.4	16.1			38.4
1997	18.9	37.1	13.3	14.0	13.3	5.6			17.0
1998	10.5	30.1	4.9	15.4	13.3	8.4			13.8
1999	18.2	26.6	20.3	12.6	9.8	18.2			17.6
2000	2.8	3.5	2.8	4.9	0.0	0.0			2.3
2001	2.1	2.1	0.0	4.2	2.1	1.4			2.0
2002	8.4	7.0	8.4	1.4	5.6	1.4			5.4
2003	20.3	28.7	2.8	11.9	18.9	6.3			14.8
2004	14.0	25.2	32.9	14.0	18.2	18.9	0.0		17.6
2005	7.7	7.7	4.9	7.0	1.4	4.9	0.0		4.8
2006	17.5	10.5	26.6	27.3	7.0	13.3	0.7	4.2	13.4
2007	8.4	2.8	11.9	9.1	2.8	7.0	0.7	2.8	5.7
2008	4.9	7.0	3.5	28.7	2.8	2.1	1.4	2.8	6.7
2009	22.4	14.0	37.8	19.6	8.4	24.5	4.2	14.7	18.2
2010	11.9	7.0	15.4	9.8	7.0	4.9	2.1	1.4	7.4
Mean	13.9	17.3	16.8	13.2	10.0	9.2	1.2	6.1	

an area is infested by these species (Skjøth et al. 2010). Thus, it can be assumed that a high presence of *Ambrosia* in the territory will increase pollen emission in the area and therefore, the amount of pollen recorded will be also higher. In other terms, the amount of pollen recorded at a particular site can be considered in general, as a reflection of the abundance of the species.

The highest mean of the APIs for the period 1994–2010 were recorded in Girona and Bellaterra (17 pollen grains for both), closely followed by Barcelona (14 pollen grains). It is important to note that these stations are located in areas where *Ambrosia* seems to be expanding and appear to be most abundant. The species are rare in the province of Tarragona, and practically non-existent in the province of Lleida (Bolòs and Vigo 1995). This may suggest that, together with the long-range transport episodes, there could also be a substantial influence of the local populations on the pollen records, particularly in the Bellaterra station, situated close to locations such as Mollet del Vallès, Montcada i Reixac, Gallecs or Montmeló, where *Ambrosia* populations have been recently reported (Fernández-Llamazares and Belmonte, *personal communication*).

3.3 Role of long-distance transport on the pollen counts

Ambrosia pollen type is very likely to be transported over long distances, as it has been shown in many European studies (Dahl et al. 1999; Saar et al. 2000; Cecchi et al. 2007). This poses a serious problem, since *Ambrosia* pollen from regions where the genus is abundant can be responsible for high *Ambrosia* pollen concentrations in places where the source plant is scarce (Stach 2006; Šikoparija et al. 2009). In this sense, and taking into account that the plant is not yet widely distributed in Catalonia, it can be assumed that much part of the *Ambrosia* pollen recorded at the Catalan aerobiological stations could be originated from allochtonous sources. Such situation has been described for Poland, where *Ambrosia* has a limited distribution (Stach et al. 2007) but the pollen is frequently noted at all the aerobiological monitoring sites (Smith et al. 2008; Kasprzyk et al. 2011). This example points out the great role of long-distance transport on the pollen counts. The use of Lagrangian back trajectory and meteorological models is very important to identify possible transport mechanisms of

Table 3 *Ambrosia* pollen absolute peaks in Catalan stations for the period 1994–2010

Year	Date	Locality	Peak concentration (pollen/m^3)	Provenance (back trajectory)	Year	Date	Locality	Peak concentration (pollen/m^3)	Provenance (back trajectory)
1994	09-Sep	Bellaterra	2.8	WNW	2006	20-Aug	Lleida	3.5	NW
1995	31-Aug	Bellaterra	5.6[a]	NNE		23-Aug	Girona	2.1	WNW
1996	02-Sep	Girona	4.2	NE		24-Aug	Lleida	4.9	NW
	08-Sep	Girona	33.6[a]	NNE		29-Aug	Lleida	2.8	WNW
		Bellaterra	23.8[a]	NNE		05-Sep	Barcelona	5.6[a]	Several, N included
		Manresa	21.0[a]	NNE			Girona	5.6[a]	Several, N included
		Barcelona	19.6[a]	NNE			Bellaterra	2.8	Several, N included
	11-Sep	Tarragona	3.5	W		06-Sep	Tarragona	2.8	SE
1997	14-Aug	Girona	3.5	Several, NE included		09-Sep	Tarragona	7.7[a]	Several, NNE included
	24-Aug	Barcelona	3.5	ENE			Girona	7.0[a]	Several, NNE included
		Bellaterra	3.5	ENE			Barcelona	6.3[a]	NNE
	16-Sep	Lleida	2.8	NNE	2007	15-Sep	Girona	4.9	Several, NNE included
1999	04-Sep	Bellaterra	7.0[a]	ENE			Tarragona	4.2	Several, NE included
		Girona	2.1	NE			Barcelona	3.5	NE
	12-Sep	Bellaterra	3.5	NE	2008	24-Aug	Lleida	4.9	NW
	13-Sep	Tarragona	9.8[a]	NE		26-Aug	Lleida	5.6[a]	NW
		Manresa	5.6[a]	NE		28-Aug	Lleida	2.8	N
		Barcelona	3.5	NE			Barcelona	2.1	N
		Lleida	2.1	NE		31-Aug	Lleida	2.8	Several
2003	16-Sep	Barcelona	7.0[a]	ENE	2009	23-Aug	Lleida	2.8	Several, N included
		Bellaterra	5.6[a]	ENE		10-Sep	Bellaterra	2.8	NE
		Lleida	4.2	NE		11-Sep	Girona	11.2[a]	NE
		Manresa	3.5	ENE			Barcelona	7.7[a]	Several, NNE included
	17-Sep	Manresa	3.5	NE			Tarragona	7.7[a]	Several, NE included
	30-Sep	Bellaterra	9.1[a]	W			Manresa	3.5	Several, NNE included
2004	07-Sep	Girona	19.6[a]	NE	2010	27-Aug	Barcelona	2.1	SW
		Bellaterra	7.0[a]	NE		28-Aug	Barcelona	2.1	WSW
		Barcelona	6.3[a]	NE		30-Aug	Girona	3.5	NW
		Lleida	4.2	Several, NNE included			Barcelona	2.8	NNW
		Tarragona	4.2	Several, NE included		01-Sep	Girona	2.8	NNE
		Manresa	2.8	Several, NE included		05-Sep	Bellaterra	2.1	Several, NNE included
	15-Sep	Tarragona	4.9	WNW		11-Sep	Girona	4.2	N

Provenances: *N* North, *NNE* North-northeast, *NE* Northeast, *ENE* East-northeast, *NNW* North-northwest, *NW* Northwest, *WNW* West-northwest, *W* West, *WSW* West-southwest, *SW* Southwest, *SE* Southeast

[a] Days in which the threshold value of 5 p/m^3 was surpassed

pollen from potential source regions, which in turn can help to accurate the forecasts of pollinosis for allergy sufferers (Skjøth et al. 2008).

During the study period, 64 peak dates were reported and most of them occurred between the 5 and the 13 September, as shown in Table 3. The backward atmospheric trajectories in these peak dates showed a predominantly northeastern (41%) and northern (36%) provenance, from the Lyon region, in France, northern Italy, and Hungary and Serbia, where the plant is highly distributed (Rybnícek and Jäger 2001). This suggests that peak dates of *Ambrosia* pollen in the Catalan stations are associated with northern and northeastern European air masses. The application of the source-receptor model revealed (Fig. 4) that the regions of east France, north Italy and Serbia are the most probable *Ambrosia* pollen origin areas. This has a relevant significance, since the species are highly widespread in the three regions. Nevertheless, to better describe the transport, a remarkable pollen event was studied in deeper detail.

Long-distance transport of *Ambrosia* pollen on the September 7, 2004, was indicated by simultaneous peaks at the majority of the Catalan aerobiological stations (Table 4). As *Ambrosia* plants are not present around most of the Catalan sampling localities—especially in Lleida and Tarragona—a simultaneous peak in most of the stations can only be explained by long-range transport of pollen. The episode of the September 7, 2004, could be considered the second most important *Ambrosia* pollen episode in Catalonia, after the one of the September 8, 1996, which had been widely studied in Belmonte et al. (2000). Girona was the sampling station where the maximum concentration (19.6 pollen/m^3) was reached during the peak date in 2004. The same situation was described for other stations such as Barcelona or Bellaterra, where the pollen counts were lower but still remarkable in comparison with the mean concentration in that period of the year.

The backward trajectories reaching Catalonia on that day came mainly from the northeastern and southern Europe, as it is showed in Fig. 5. As shown in Makra et al. (2005), early September is the period of the year with the highest *Ambrosia* pollen levels in Hungary. The synoptic situation during the episode

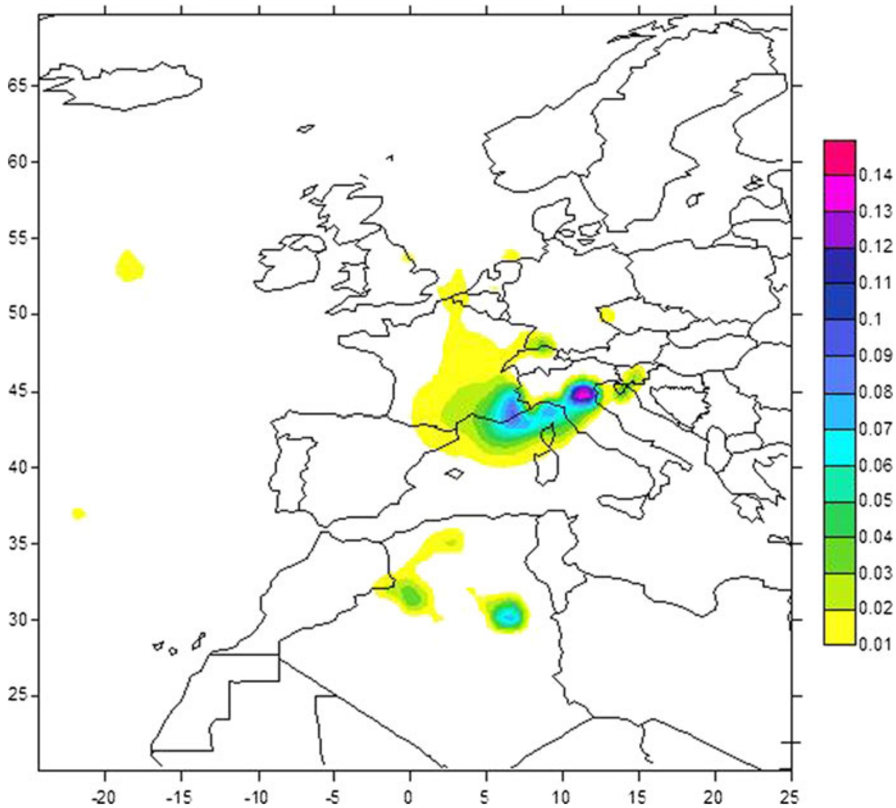

Fig. 4 *Ambrosia* concentration field (p/m^3) for the period 1997–2009 (25 June to 10 October) computed at the height of 1,500 m

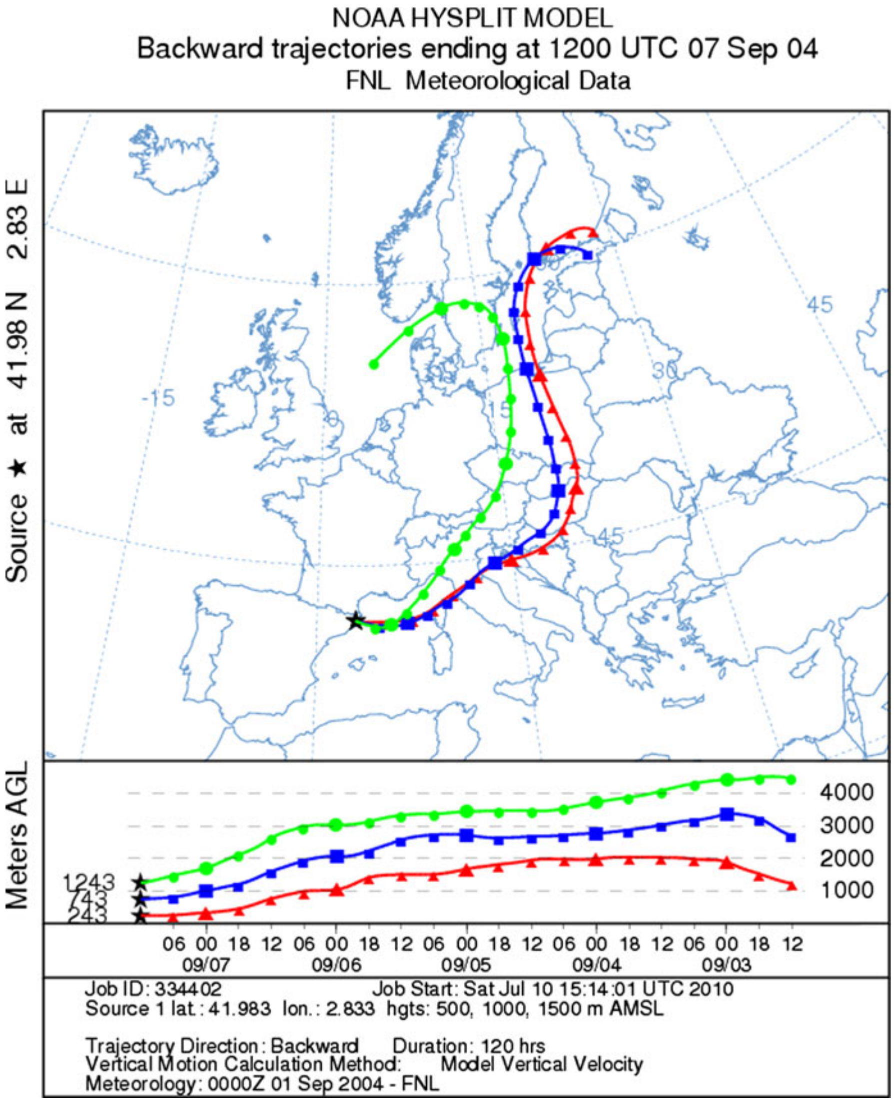

Fig. 5 Backward trajectories reaching Catalonia at 12 UTC the September 7, 2004

was characterized by two high-pressure systems centered in the British Islands and eastern Europe, respectively, which induced a north-easterly air-mass flux over Catalonia, reinforced by the presence of a weak low over the Iberian Peninsula, as showed in Fig. 6. Similar results were found for two peak pollen events in Central Italy, in which the pollen was transported from Serbia and Hungary (Cecchi et al. 2007).

There is not a scientific agreement on the threshold level that triggers allergic reactions in sensitive patients. Regarding *Ambrosia* pollen, some authors consider that this value is over 20 p/m^3 of air (Juhász 1995 *for Hungary*; Jäger 1998 *for Austria*), while other point out a threshold of 5 p/m^3 as the daily concentration enough to elicit allergy troubles in a sensitized population (Thibaudon 2002; Taramarcaz et al. 2005 *for France*). Taking into account the low incidence of airborne *Ambrosia* pollen in Catalonia and that usually the pollen thresholds for triggering allergy symptoms vary depending on the airborne pollen levels, it can be considered that in Catalonia, low concentrations can be enough for causing problems to a sensitized population and for this reason, we considered the 5 p/m^3 threshold. Taking this threshold into account, there have been 23 days under risk of allergy in the eight Catalan stations and the 106 yearly series studied in the period 1994–2010. Table 3 shows that the

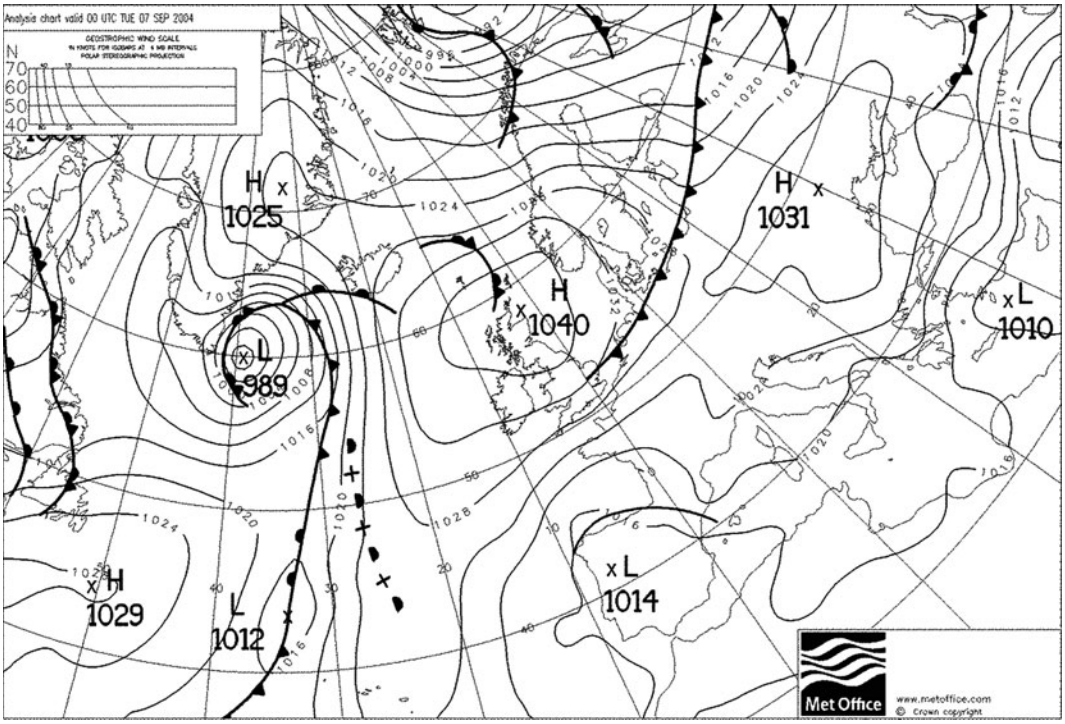

Fig. 6 Synoptic chart corresponding to the mean sea level pressure for the September 7, 2004

threshold has been surpassed six times in Barcelona and Bellaterra, five in Girona, three in Tarragona, two in Manresa and one in Lleida and that it has never been reached in Roquetes-Tortosa and Vielha. The expansion of the species may increase the number of days where this threshold is surpassed.

4 Conclusions

Ambrosia pollen type is not showing an increasing trend in the atmosphere of Catalonia for the period 1994–2010. However, the episodes of long-range transport of this pollen seem to be increasing in number in the last years and may be enhancing the sensitivity in the population, as well as contributing to the outcome of the species over the territory. There could also be a certain influence of the local populations on the pollen counts, especially in the province of Barcelona, where *Ambrosia* seem to be more and more abundant. Although *Ambrosia* is still rare in Catalonia, it can become a serious menace to public health due to the high allergenic potential of its pollen and the cross-reactivity with other pollen. This gives cause for concern to aerobiologists and that is the reason why the authors propose the following management policies: (a) Spain should participate in the European networks for the control of *Ambrosia*; (b) The Spanish Aerobiological Network (Red Española de Aerobiología, REA) should consider counting *Ambrosia* pollen type on a daily basis, in order to contribute to a better knowledge of the tendencies of the genus throughout the territory; (c) The expansion of *Ambrosia* in Catalonia—and therefore, in Spain—must be closely surveyed, as some of the new populations detected appear to be increasing in size at high growing rates; (d) The Catalan Government should start to think forward to the eradication of the *Ambrosia* populations in the territory—particularly, in the Besòs riverbanks and in the beaches of El Prat del Llobregat—before the expansion of the genus is too wide to face its management.

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