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Atmospheric invasion of non-native pollen in the Mediterranean region[1]

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Most research on the impacts of plant invasion focuses on native plant performance, community structure, and ecosystem functioning. Some non-native species can also pose a risk to human health. One such risk is the allergenic nature of the pollen of some introduced plants. We examined whether patterns of airborne pollen differed between non-native and native taxa by summarizing data from seven Spanish Mediterranean localities monitored over 13 yr. The pollen spectra contained 27 native pollen taxa and 18 non-native taxa. Even though pollen from native taxa were more diverse and were present longer in the atmosphere than the non-native, in some years neither the prevalence of the two nor their weekly maximum pollen values differed significantly. However, maximum values for non-native taxa were found earlier in the season than for native pollen. A small percentage of non-native pollen includes pollen from introduced taxa that have not invaded natural habitats (e.g., ornamental plants). Non-native pollen has a larger proportion of allergenic pollen than native pollen. Therefore, the results reveal that the presence of non-native airborne pollen from naturalized and non-naturalized plant species increases the total amount of airborne allergenic pollen grains and the period of allergenic susceptibility.

Key words: aerobiology; alien plants; allergenic pollen; Catalonia; phenology; plant invasions; pollen diversity.

Biological invasions are a component of global change with major ecological impacts on the conservation of native species and the integrity of natural ecosystems worldwide (Mack et al., 2000; Levine et al., 2003). Biological invasions are also recognized to have important economic costs (Pimentel et al., 2000; Pimentel, 2002), especially by reducing crop and pasture production, altering infrastructure use, increasing restoration expenses, and decreasing the aesthetic value of natural areas (McNeely, 2001). Some alien species are also toxic, poisonous, infectious, or allergenic, causing human health problems (Groves, 2002). For example, the unintentional introduction of pathogen microbes has a serious impact on human health (Kim, 2002). However, quantification of the impact of non-native higher organisms (i.e., plants and animals) on human health has been mostly anecdotal. Allergenic pollen can be of prime importance in health problems caused by non-native plants (Potter and Cadman, 1996). Furthermore, allergenic airborne pollen can interact with other components of environmental global change in a synergic way increasing the risks to public heath. For example, warming and increased atmospheric CO_2 increase ragweed (*Ambrosia* spp.) pollen production due to an increase in the number of floral spikes per plant (Ziska and Caulfield, 2000; Wayne et al., 2002; Wan et al., 2002). Therefore, climate change can exacerbate the risks of this highly allergenic species.

It is also relevant to note that the risk of non-native airborne pollen can be assessed independently of the invasion status of the plant. That is, even if the non-native plant in question (or parts of it, such as grain or fodder) have only been recently introduced, are confined to restricted areas (e.g., crops, gardens or containers), have not been naturalized (and probably will never be), and do not pose any ecological impact, allergenic pollen disperses into the atmosphere and can cause health problems (McLean et al., 1991).

The region east of the Mediterranean basin is one with the highest biological diversity in Europe (Médail and Quézel, 1997). Its plant diversity is associated with the biogeographic location of the Iberian Peninsula and the wide range of habitats and pedological diversity. The Spanish peninsula is also rich in alien flora with more than 600 naturalized plant species (13% of the total flora), the majority of which are from America or from other regions of Europe (Vilà et al., 2001). Most of these alien species are generally common in disturbed or manmade habitats. Indeed, 68% of naturalized species are pioneer species that colonize ruderal habitats or infest crops (Vilà et al., 2001). This high native and non-native taxonomic diversity is also represented in the pollen spectra of this region. Furthermore, because the aim of aerobiological stations is to disseminate information about potential pollen allergies, they are placed in urban areas where pollen from alien ornamental plants can also be captured.

In this study, we summarize data for native and non-native airborne pollen data for seven Mediterranean localities of Catalonia (northeast Spain) monitored from 1989 to 2001. This analysis quantifies for the first time the diversity, abundance, and phenology of non-native airborne pollen at the regional scale and highlights the hazard that non-native plant species pose to human health by means of the capacity of some pollen taxa to cause allergic reactions (e.g., rhinitis, conjunctivitis, asthma) in sensitized people. The questions we explored are: (1) What is the diversity of non-native airborne pollen? (2) What is the proportion of non-naturalized non-native airborne pollen? (3) Do native and non-native airborne pollen peak at the same time of the year? (4) Do non-native airborne pollen lengthen the period of allergy risk? And finally, (5) has non-native airborne pollen increased through time?

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TABLE 1. Geographical and climatic characteristics of sampling stations in Catalonia, Spain.

Geographical characteristics				Climatic characteristics		
Sampling stations	Altitude (m a.s.l.)	Latitude/ Longitude	Environment	Mean annual temperature (°C)	Annual rainfall (mm)	Phytoclimates (Allué, 1990)
Barcelona	12	41°24′ N, 02°11′ E	urban	16.4	593	Fresh-Tethyc-semiarid
Bellaterra	190	41°33′ N, 02°07′ E	rural/urban	15.2	594	Fresh-Continental Oriental-semihumid
Girona	70	41°59′ N, 02°60′ E	urban	15.0	740	Fresh-Continental Oriental-semihumid
Lleida	221	41°37′ N, 00°37′ E	urban	15.1	385	Fresh-Transitional-semiarid
Manresa	238	41°43′ N, 01°50′ E	rural	13.6	619	Fresh-Continental Oriental-semihumid
Roquetes	50	40°49′ N, 00°58′ E	rural/urban	16.8	576	Fresh-Tethyc-semiarid
Tarragona	20	41°07′ N, 01°15′ E	urban	15.8	478	Fresh-Tethyc-semiarid

MATERIALS AND METHODS

The Aerobiological Network of Catalonia (Xarxa Aerobiològica de Catalunya, XAC, http://www.uab.es/l-analisis-palinologiques/aerobio.htm) has been in continuous service since 1987. During the period 1989–1995, the Catalan atmosphere was sampled by the Cour method (Cour, 1974) at Barcelona, Bellaterra, Girona, Lleida, Manresa, Tarragona, and Roquetes. Since 1994 in Barcelona and Bellaterra and 1996 in Girona, Lleida, Manresa, and Tarragona, the network has used the Hirst methodology (Hirst, 1952). The reason for this change in the sampling methodology was to adapt the Catalan network to the Spanish Network on Aerobiology (Red Española de Aerobiología, REA) created in 1992. Details on geographic and climatic characteristics of these localities can be found in Table 1 and Fig. 1.

Cour and Hirst atmospheric samplers were designed to capture biological atmospheric particles from known volumes of air at weekly and daily rates, respectively. Their developers have proposed associated analytical methodologies for identifying and counting the trapped taxa. Identification is always based on the morphological characteristics of the pollen when observed through light microscopes. Thus, results obtained by these methods are expressed as the mean number of pollen grains per cubic meter of air during the exposure time period.

As mentioned, for logistical reasons we did not collect the airborne pollen with the same methodology for the entire period. Literature comparing the Cour and Hirst methods and values is scarce. A very precise comparison is in preparation (I. Ferrera, M. Calleja, and J. Belmonte, unpublished data). The two sampling methods provide essentially the same parameters, but as stated in Belmonte et al. (2000), the values measured for some parameters might vary. Therefore, in this paper, values from Hirst and Cour methods were not mixed in the same statistical analysis.

We compared airborne pollen parameters of native and non-native taxa. We also looked for differences within non-native taxa, that is, between naturalized taxa (i.e., established taxa that reproduce without human intervention) and non-native taxa that have not established themselves in natural or semi-natural ecosystems and remain as ornamentals or plantations (introduced, hereafter).

For the data obtained with the Cour method (1989–1995) and the Hirst method (1996–2001) separately, differences between native and non-native pollen in the annual pollen index (i.e., total number of pollen grains per year established as the sum of the corresponding mean weekly pollen concentrations), pollen diversity (calculated as the Shannon index), number of weeks per year with airborne pollen, weekly maximum concentration (i.e., highest value among the mean weekly concentrations of the year), and date of the week with the weekly maximum concentration (taking into account that the first week of the year is the one containing the first Thursday in the year) were compared with a repeated measures analysis of variance (ANOVA) with pollen origin (native and non-native) as the fixed factor and year as the repeated measure. We chose to compare pollen diversity instead of pollen richness in order to take into account richness of taxa and their representation.

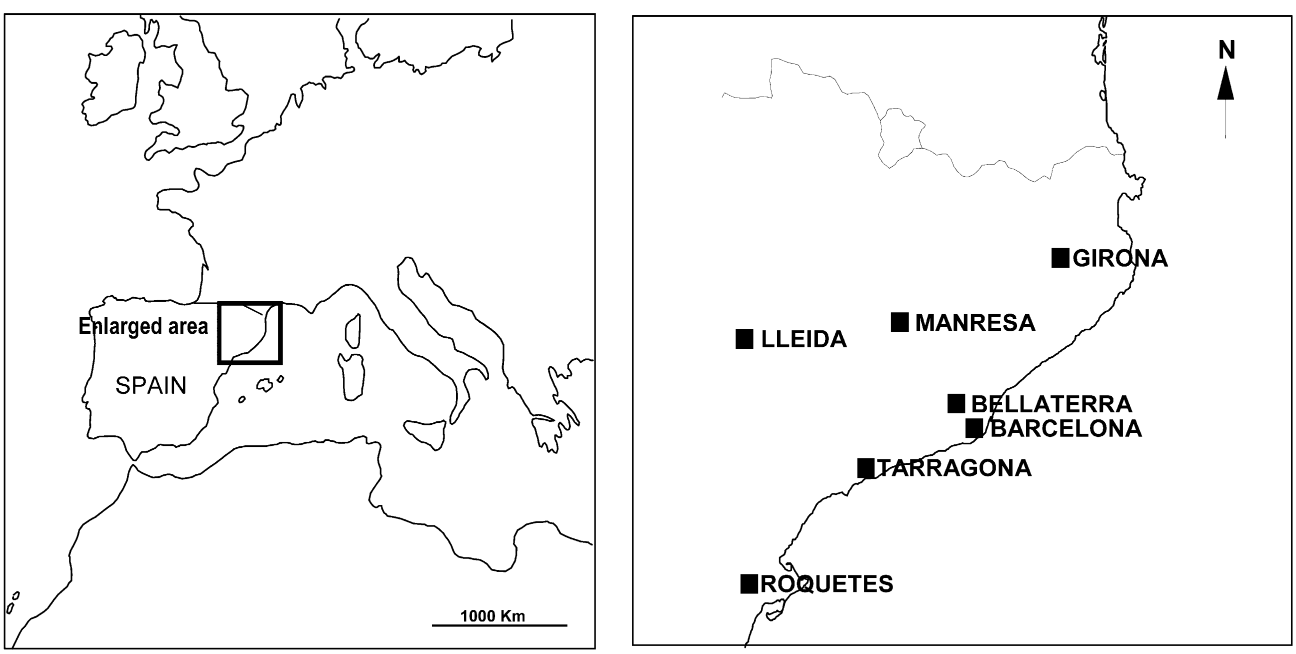

Fig. 1. Maps of the locations of the aerobiological sampling sites in Catalonia, Spain.

TABLE 2. Taxa of native and non-native airborne pollen grains identified in Catalonia from 1989 to 2001.

Pollen taxa	Family	Origin	Allergenicity[a]
Acacia	Mimosaceae	Naturalized	Allergenic
Acer	Aceraceae	Introduced	Allergenic
Aesculus	Hippocastanaceae	Introduced	Unknown
Ailanthus	Simaroubaceae	Naturalized	Non-allergenic
Alnus	Betulaceae	Native	Allergenic
Arbutus	Ericaceae	Native	Non-allergenic
Buxus	Buxaceae	Native	Non-allergenic
Calluna	Ericaceae	Native	Non-allergenic
Castanea	Fagaceae	Naturalized	Allergenic
Casuarina	Casuarinaceae	Introduced	Allergenic
Cedrus	Pinaceae	Introduced	Non-allergenic
Celtis	Ulmaceae	Naturalized	Non-allergenic
Ceratonia	Papilionaceae	Naturalized	Non-allergenic
Cistaceae[b]	Cistaceae	Native	Non-allergenic
Citrus	Rutaceae	Introduced	Non-allergenic
Coriaria	Coriariaceae	Native	Unknown
Ephedra	Ephedraceae	Native	Non-allergenic
Erica	Ericaceae	Native	Non-allergenic
Ericaceae[b]	Ericaceae	Native	Non-allergenic
Eucalyptus	Myrtaceae	Introduced	Allergenic
Fagus	Fagaceae	Native	Unknown
Hedera	Araliaceae	Native	Non-allergenic
Helianthus	Asteraceae	Introduced	Allergenic
Ilex	Aquifoliaceae	Native	Non-allergenic
Juglans	Juglandaceae	Naturalized	Unknown
Lotus	Papilionaceae	Native	Non-allergenic
Lygeum	Poaceae	Native	Allergenic
Mercurialis	Euphorbiaceae	Native	Allergenic
Moraceae[b]	Moraceae	Naturalized	Allergenic
Myoporum	Myoporaceae	Introduced	Non-allergenic
Olea	Oleaceae	Native	Allergenic
Phillyrea	Oleaceae	Native	Allergenic
Pistacia	Anacardiaceae	Native	Allergenic
Plantago	Plantaginaceae	Native	Allergenic
Platanus	Platanaceae	Naturalized	Allergenic
Poterium	Rosaceae	Native	Non-allergenic
Quercus evergreen	Fagaceae	Native	Allergenic
Rhamnus	Rhamnaceae	Native	Non-allergenic
Rosmarinus	Lamiaceae	Native	Non-allergenic
Schinus	Anacardiaceae	Introduced	Unknown
Reseda	Resedaceae	Native	Non-allergenic
Sambucus	Caprifoliaceae	Native	Unknown
Thymelaeaceae[b]	Thymelaeaceae	Native	Non-allergenic
Vitis	Vitaceae	Native	Non-allergenic
Xanthium	Asteraceae	Naturalized	Allergenic

[a] Based on the capacity of some pollen taxa to cause allergic reactions (e.g., rhinitis, conjunctivitis, asthma) in sensitized people (Lewis et al., 1983; García-Ortega et al., 1992).
[b] It is not possible to identify to genus.

Repeated measures ANOVA was also conducted to compare differences between native and non-native allergenic pollen (i.e., the sum of values of the pollen taxa in the respective categories of native and non-native classified as allergenic in Table 2) and differences between naturalized and introduced taxa.

Data were log and square transformed when necessary to meet the assumptions of parametric analysis. Spearman correlation tests between the pollen parameters and year were also performed to test for temporal trends.

RESULTS

Total pollen—In the airborne pollen from the monitoring stations we identified 27 native and 18 non-native (nine introduced and nine naturalized) pollen types (Table 2). However, the diversity of non-native pollen was not significantly different than that of native pollen in most years (Table 3, Fig. 2). Although pollen from non-native taxa was present in the atmosphere for a shorter duration than native pollen (Fig. 3), non-native pollen accounted for more than 17% of total airborne pollen, and only in some years was non-native pollen less abundant than native pollen (Table 3, Fig. 4).

Although in most years weekly maximum pollen concentration did not differ significantly between native and non-native pollen taxa, non-native taxa reached their weekly maximum earlier than did pollen from native taxa (Table 3, Fig. 5).

Non-native pollen—Pollen diversity of naturalized vs. introduced taxa was not significantly different (Table 4). For 1996–2001, the number of weeks with airborne pollen from naturalized taxa was also greater than for introduced taxa (Table 5).

The total number of pollen grains per year from naturalized

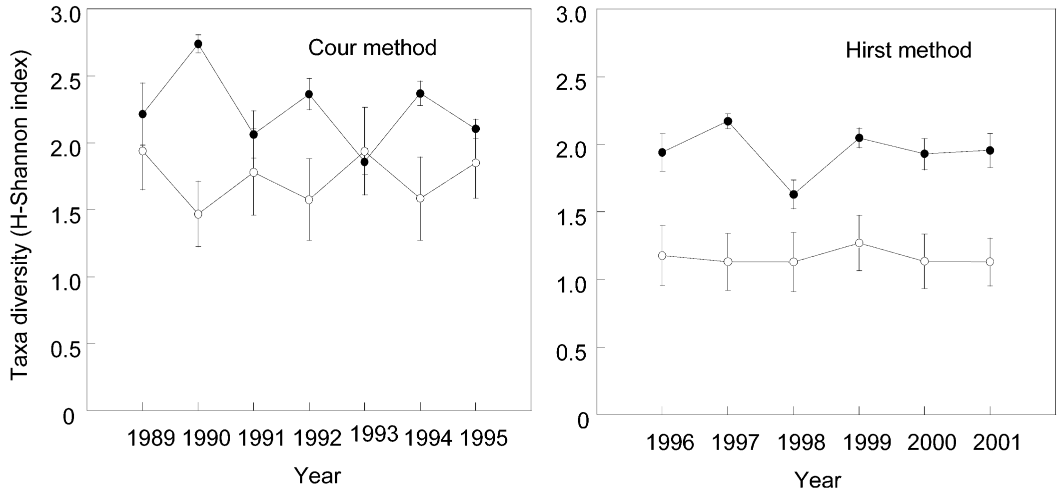

Fig. 2. Mean (± SE) values for diversity (Shannon index) of native (filled circles) and non-native (open circles) airborne pollen in Catalonia. Airborne pollen was estimated by the Cour method from 1989 to 1995 and by the Hirst method from 1996 to 2001.

taxa was always larger than from introduced taxa (Table 5). The average percentage of airborne pollen grains from introduced taxa was only 15.35 ± 1.30% of the total non-native count from 1989–1995 and 6.08 ± 0.83% from 1996–2001. Maximum concentrations were also significantly lower in introduced taxa (Tables 4, 5). Dates of the maximum weekly concentrations were significantly different from 1989–1995 (i.e., introduced pollen had their weekly maximum later than naturalized pollen), but not from 1996–2001 (Table 4).

Allergenic pollen—While only 29% of the native taxa represented in the pollen spectra can cause allergies, nearly 50%

TABLE 3. Repeated measures analysis of variance comparing patterns of native and non-native airborne pollen in Catalonia. Airborne pollen was estimated by the Cour method from 1989 to 1995 and by the Hirst method from 1996 to 2001.

	1989–1995					1996–2001				
	All pollen			Allergenic pollen		All pollen			Allergenic pollen	
Variable	df	*F*	*P*	*F*	*P*	df	*F*	*P*	*F*	*P*
Diversity[a]										
Origin	1,60	1.37	0.29	6.45	0.03	1,50	13.50	0.004	8.12	0.02
Year	6,60	0.13	0.99	0.72	0.64	5,50	4.33	0.002	3.42	0.01
Origin × year	6,60	2.91	0.02	2.37	0.04	5,50	3.14	0.01	3.53	0.008
No. weeks present										
Origin	1,60	5.55	0.06	11.32	0.007	1,50	15.21	0.003	26.88	0.0004
Year	6,60	4.48	0.002	3.15	0.009	5,50	2.27	0.6	2.90	0.02
Origin × year	6,60	1.89	0.109	1.85	0.104	5,50	1.92	0.11	1.40	0.24
Annual index[b]										
Origin	1,60	8.01	0.03	6.004	0.03	1,50	0.59	0.46	0.45	0.52
Year	6,60	4.34	0.002	2.39	0.04	5,50	13.33	<0.0001	18.69	<0.0001
Origin × year	6,60	4.52	0.002	4.96	0.0004	5,50	1.52	0.20	1.58	0.18
Weekly maximum[c]										
Origin	1,60	3.23	0.12	2.37	0.15	1,50	0.16	0.69	0.94	0.35
Year	6,60	1.74	0.14	1.42	0.22	5,50	6.18	<0.0002	1.91	0.11
Origin × year	6,60	4.27	0.002	5.06	0.003	5,50	1.47	0.22	0.59	0.71
No. week of maximum										
Origin	1,60	304.82	<0.0001	947.73	<0.0001	1,50	154.99	<0.0001	154.99	<0.0001
Year	6,60	2.55	0.037	5.46	0.001	5,50	16.56	<0.0001	16.56	0.0001
Origin × year	6,60	0.75	0.61	3.23	0.008	5,50	4.95	0.0009	4.95	0.0009
Percentage allergenic										
Origin	1,60	0.16	0.70			1,50	16.12	0.0025		
Year	6,60	1.41	0.23			5,50	5.18	0.0007		
Origin × year	6,60	3.21	0.008			5,50	10.64	<0.0001		

[a] Calculated as the Shannon index.
[b] Total number of pollen grains per year.
[c] Highest value among the mean weekly concentrations of the year.

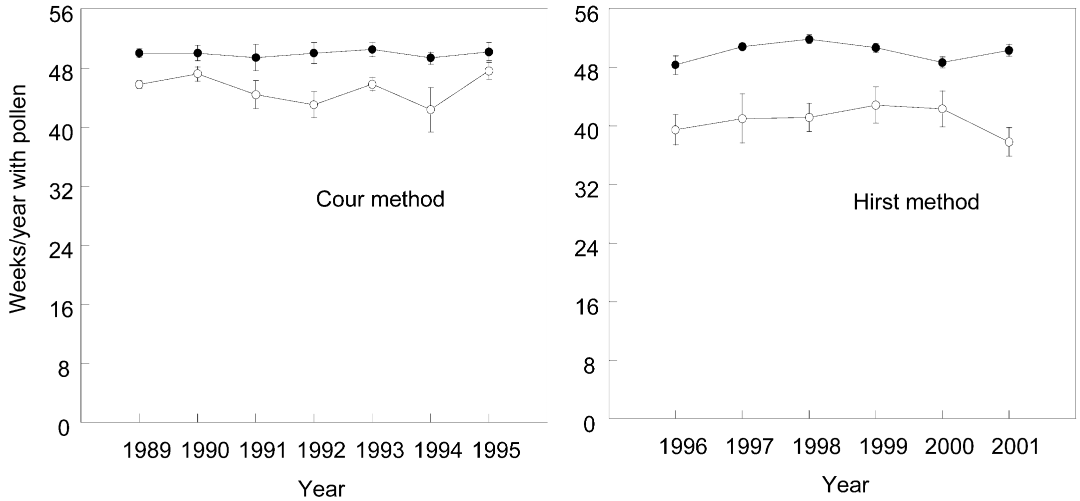

Fig. 3. Mean (± SE) number of weeks per year in which there is native (filled circles) and non-native (open circles) airborne pollen in Catalonia. Airborne pollen was estimated by the Cour method from 1989 to 1995 and by the Hirst method from 1996 to 2001.

of the non-native taxa are allergenic (Table 2). Allergenic pollen grains are extremely abundant. From 1989 to 1995, 90.01 ± 1.18% of the airborne pollen from non-native taxa was allergenic, while allergenic native airborne pollen accounted for 87.90 ± 1.81% of the total (Fig. 6). The values from the period 1995–2001 were much higher: 98.32 ± 0.19% of non-native pollen grains were allergenic, a percentage significantly higher than for native pollen (94.59 ± 0.47%) (Table 3, Fig. 6). Differences between native and non-native allergenic airborne pollen followed the same patterns as those previously described for total native and non-native airborne pollen (Table 3), except that native allergenic pollen diversity was significantly higher than for non-native taxa in both periods (Table 3). The percentage of allergenic pollen grains of naturalized taxa was significantly higher than for introduced taxa in both periods (Table 5).

Temporal variation—Spearman correlation analyses showed that there were not significant patterns for a decrease or increase in pollen taxa throughout the years, except for a decrease in native pollen diversity from 1989 to 1995 (R_{ho} = 0.399, P = 0.012) and a decrease in the duration of pollen prevalence (R_{ho} = 0.532, P = 0.0009) for the same period (Table 3). For most parameters, we found an interaction between pollen origin and year. This interaction did not denote a reverse pattern in the differences described earlier, except for higher weekly maximum values for non-native compared to native taxa in 1990. The interaction can be explained because differences between native and non-native airborne pollen were statistically nonsignificant in some years (Figs. 2–6).

DISCUSSION

Of the pollen collected during the last 13 yr, 18 taxa representing 20% of all airborne taxa in Catalonia were identified as non-native. In certain years, these few non-native taxa can produce as much airborne pollen as can the highly diverse native vegetation. Most airborne pollen belongs to wind-pollinated taxa, a pollination regime that is not always the most common among invasive plants (Pysek et al., 1999; Lloret et

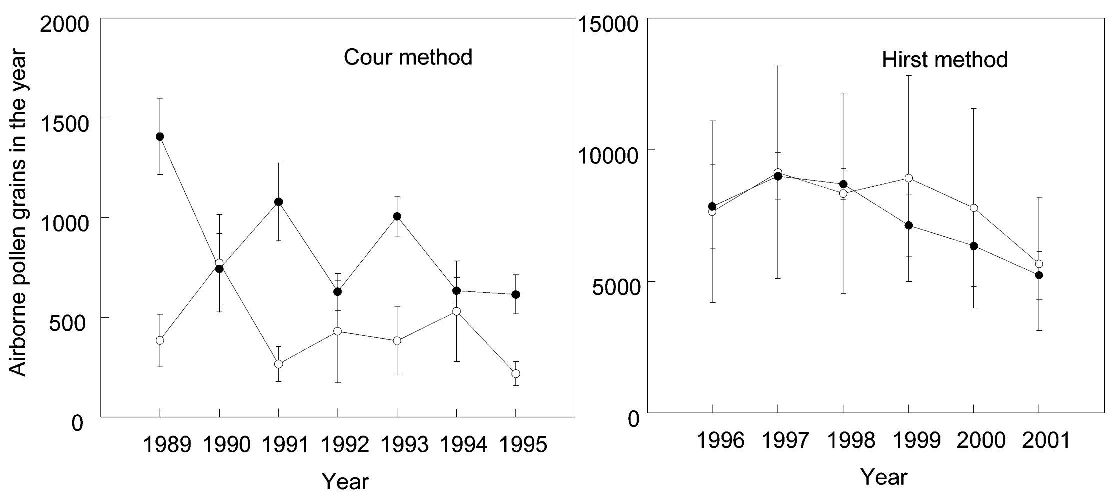

Fig. 4. Mean (± SE) total of airborne pollen grains of native (filled circles) and non-native (open circles) taxa in Catalonia. Estimates were made by the Cour method from 1989 to 1995 and by the Hirst method from 1996 to 2001.

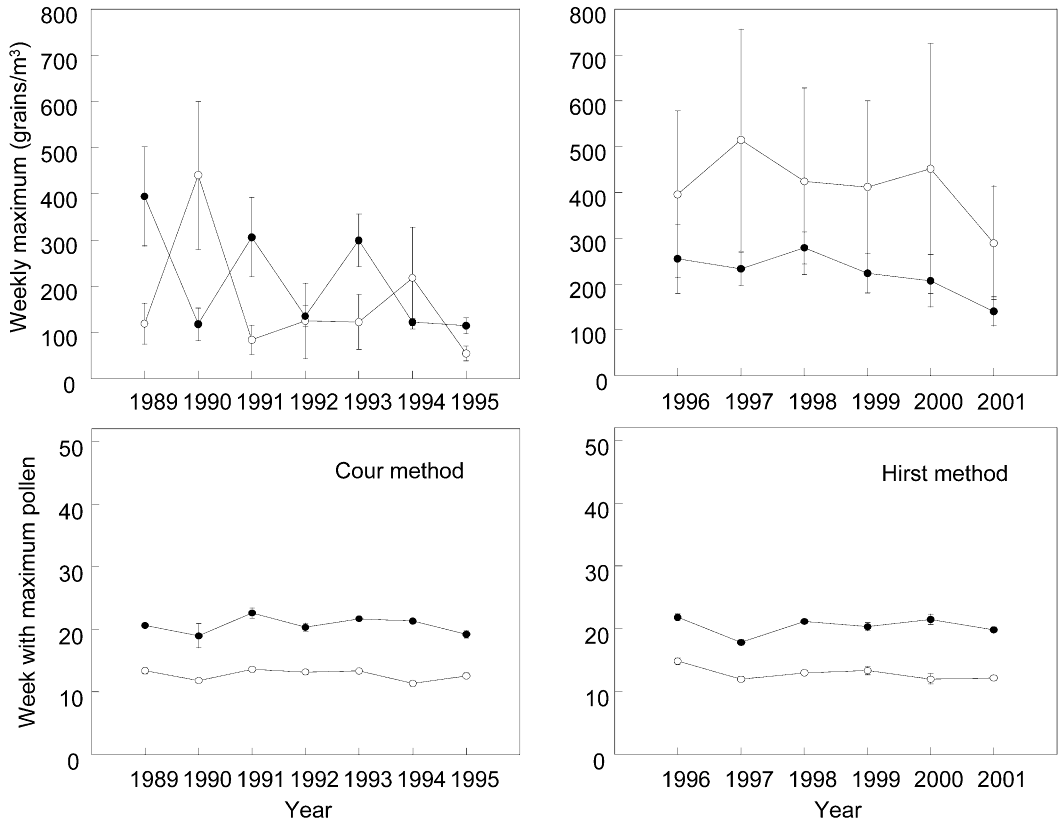

Fig. 5. Mean (± SE) of weekly maximum concentrations of airborne pollen and the number of the week with the maximum number of native (filled circles) and non-native (open circles) taxa in Catalonia. Estimates were made by the Cour method from 1989 to 1995 and by the Hirst method from 1996 to 2001.

al., 2004). The higher average pollen prevalence in non-native taxa is mainly due to the copious pollen production of *Platanus* spp. and species of the Moraceae (including *Morus* and *Broussonettia*). These species produce even more pollen than the native evergreen *Quercus* spp. and *Olea europaea* L., taxa which as a result of their broad distribution and abundance in Catalonia produce large quantities of pollen.

A low but persistent percentage of non-native airborne pollen grains belong to introduced species that have not invaded the region. Obviously, the taxonomic richness of worldwide-introduced taxa is much larger than that of naturalized and invasive taxa, especially if we consider the great variety of taxa that have been intentionally introduced as domestic livestock forage, restoration vegetation, and ornamentals in the last century (Mack, 2001). However, according to our airborne survey, the greater number of introduced vs. naturalized spe-

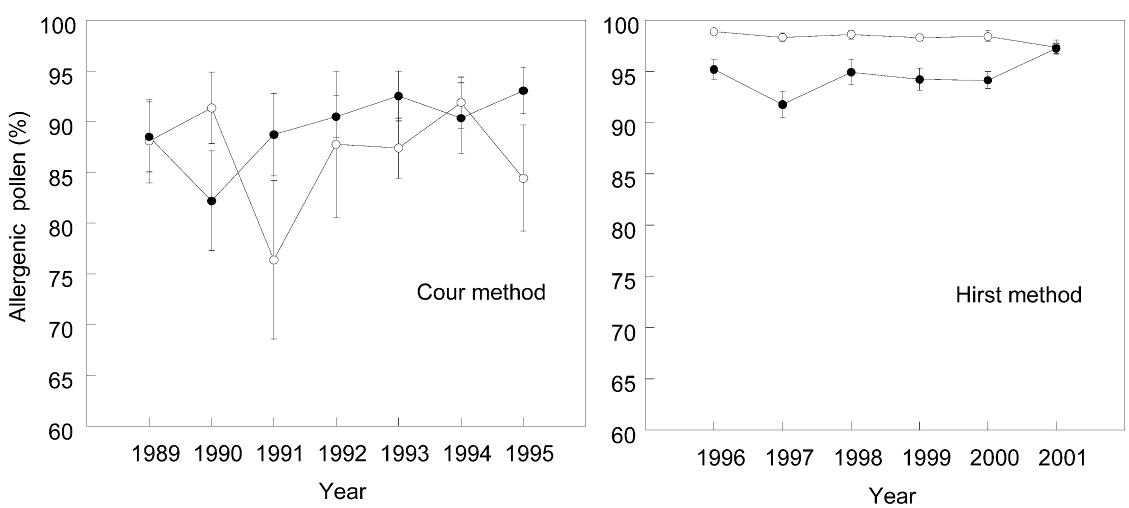

Fig. 6. Mean (± SE) percentage of allergenic pollen grains of total annual native (filled circles) and non-native (open circles) taxa in Catalonia. Totals were estimated by the Cour method from 1989 to 1995 and by the Hirst method from 1996 to 2001.

TABLE 4. Repeated measures analysis of variance comparing patterns of introduced and naturalized airborne pollen in Catalonia. Airborne pollen was estimated by the Cour method from 1989 to 1995 and by the Hirst method from 1996 to 2001.

Variable	1989–1995			1996–2001		
	df	*F*	*P*	df	*F*	*P*
Diversity[a]						
Origin	1,60	3.21	0.10	1,50	4.94	0.05
Year	6,60	1.15	0.34	5,50	2.94	0.02
Origin × year	6,60	1.11	0.37	5,50	2.12	0.08
No. Weeks present						
Origin	1,60	2.00	0.19	1,50	17.96	0.002
Year	6,60	4.34	0.001	5,50	4.57	0.002
Origin × year	6,60	0.11	0.99	5,50	1.65	0.16
Annual index[b]						
Origin	1,60	10.54	0.009	1,50	46.46	<0.0001
Year	6,60	2.90	0.02	5,50	6.88	<0.0001
Origin × year	6,60	1.27	0.28	5,50	1.53	0.20
Weekly maximum[c]						
Origin	1,60	9.49	0.02	1,50	43.37	<0.0001
Year	6,60	2.77	0.02	5,50	2.10	0.08
Origin × year	6,60	1.16	0.34	5,50	1.42	0.23
No. week of maximum						
Origin	1,60	8.97	0.01	1,50	2.02	0.18
Year	6,60	2.16	0.06	5,50	0.30	0.91
Origin × year	6,60	1.62	0.16	5,50	0.87	0.51
Percentage allergenic						
Origin	1,60	7.99	0.02	1,50	37.50	<0.0001
Year	6,60	6.67	<0.0001	5,50	1.62	0.17
Origin × year	6,60	5.34	0.0002	5,50	1.19	0.33

[a] Calculated as the Shannon index.
[b] Total number of pollen grains per year.
[c] Highest value among the mean weekly concentrations of the year.

cies does not translate into higher pollen richness of introduced compared to naturalized taxa. This might suggest that a certain abundance of a species is required in order for its pollen to be detected apart from considering the specific differences in pollen production and dispersal of the species.

Non-native taxa reached its maximum at the end of March. In contrast, peaks for native taxa were in mid-May, suggesting that the flowering phenology of non-native taxa is more advanced than that of native taxa. The lack of coincidence of maximum values between native and non-native pollen implies that the introduction of non-native plants increases the period of allergy risk. It is striking to notice that although only 38% of the taxa are known to be allergenic, most pollen grains circulating in the atmosphere are allergenic. Moreover, non-native taxa have a higher proportion of allergenic pollen than native taxa. These results draw attention to the risk that non-native plant species can pose to human health. Until now most efforts in the study of the risks and hazards of plant invasions have emphasized the impact on ecological processes, such as in reducing survival or growth of native plants and altering trophic structure or nutrient cycling (Parker et al., 1999; Levine et al., 2003). However, here we show that even some intentionally introduced non-native plants that are not invading native ecosystems also have the potential to affect human health.

Recently, the study of biological invasions has been ap-

TABLE 5. Characteristics of introduced and naturalized airborne pollen patterns in Catalonia. Values are means ± SE across years and localities. Airborne pollen was estimated by the Cour method from 1989 to 1995 and by the Hirst method from 1996 to 2001. See Table 4 for statistical significance.

Variable	1989–1995		1996–2001	
	Introduced	Naturalized	Introduced	Naturalized
Diversity[a]	1.69 ± 0.09	1.08 ± 0.09	1.43 ± 0.10	0.84 ± 0.06
No. weeks present	33.68 ± 0.85	39.29 ± 1.05	11.49 ± 0.95	21.46 ± 1.09
Annual index[b]	46.42 ± 5.80	381.25 ± 70.92	223.44 ± 16.85	7689.27 ± 1381.68
Percentage of total	1.07 ± 0.10	8.18 ± 1.27	0.64 ± 0.06	17.06 ± 2.38
Weekly maximum[c]	17.59 ± 3.30	161.73 ± 33.71	10.27 ± 1.10	410.10 ± 79.42
No. week of maximum	25.50 ± 2.42	12.82 ± 0.19	18.42 ± 1.99	12.97 ± 0.27
Percentage allergenic	69.70 ± 3.50	90.78 ± 1.80	94.64 ± 2.14	98.98 ± 0.14

[a] Calculated as the Shannon index.
[b] Total number of pollen grains per year.
[c] Highest value among the mean weekly concentrations of the year.

proached from an epidemiological perspective (Smith et al., 1999; Mack et al., 2000). The study of patterns of airborne pollen and the risk they pose to human health is an excellent starting point for such a joint venture. We strongly advocate that if we are going to advise that policies and management practices should address biological invasions, more research should be conducted beyond the traditional studies focusing on the ecological impacts of well-established non-native species invading natural ecosystems. Here we have demonstrated that the introduction of non-native species, even if they have not become naturalized, can increase and extend the period of allergenic airborne pollen prevalence.

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