

Temporal trends of the airborne fungal spores in Catalonia (NE Spain), 1995–2013

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Abstract To establish the trends in the period 1995–2013 of the annual fungal spore index of 20 taxa in 8 aerobiological sites of Catalonia, located in 4 phytoclimates, we use the nonparametric Spearman's Rho and Mann–Kendall tests; when significant, we calculate the magnitude of the change applying the Theil–Sen estimator. We analyze whether the proportional annual change is significantly different from zero, according to phytoclimate, station, and spore taxon, with the Wilcoxon–Mann–Whitney test. *Cladosporium*, Coprinaceae and *Agrocybe* are the most prevalent taxa. The proportional annual change analysis shows that 12 taxa present significant increasing trends and 2 decreasing, that the Fresh-Continental Oriental-Humid phytoclimate and *Agrocybe* show the highest significant increase, while Roquetes-Tortosa (Fresh-Tethyc-Semi-arid phytoclimate) and *Torula* the lowest. The greater

significant decreasing proportional annual change corresponds to *Drechslera–Helminthosporium* and the lesser to *Curvularia*, and there are no results per phytoclimate and locality. The diversity of characteristics of the sites studied brings the opportunity to evaluate the variability of the fungal values and the magnitude of their change across the study period as depending on the intensity of the land use (urbanization versus agriculture) and the distance to the sea (inland versus littoral), but the effect of the change of the meteorological patterns in the recent years is not negligible. The increasing temperatures and precipitation instability established as effects of the climate change in Catalonia in the last 50 years could be stimulating the sporulation in mountain areas and affecting it in the southern Catalan littoral, thus affecting spore counts.

Keywords Annual fungal spore index · Mann–Kendall test · Spearman's Rho test · Theil–Sen estimator · Proportional annual change · Wilcoxon–Mann–Whitney test

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1 Introduction

Fungal spores are an airborne biological component that can be found in any time of the year (Lacey 1981; Burch and Levetin 2002). Although spore levels vary according to climate, season, day-night, vegetation and location (Grinn-Gofroń and Strzelczak 2008a), their concentrations in the atmosphere are the result of

a wide range of complex interrelated environmental and biological factors such as the growth of the fungus and the differentiation of the spore. Their presence can cause human health problems (mainly allergies) and crop infections (phytopathology). Simon-Nobbe et al. (2008) reported that more than 80 mold genera have been shown to induce type I allergies in susceptible persons. Several authors have related the presence of spores with losses in crops, for example *Botrytis* in strawberry (Blanco et al. 2006) and in vineyard (Oliveira et al. 2009a; Rodríguez-Rajo et al. 2010; Fernández-González et al. 2012; Leyronas and Nicot 2013), *Alternaria* in olive (Moral et al. 2008) or *Phakopsora* in soybean (Tao et al. 2009).

Although many studies have shown the relationship between meteorological conditions and airborne spores (i.e., Grinn-Gofroń and Strzelczak 2011; De Linares et al. 2010; Escuredo et al. 2011; Recio et al. 2012), few studies have examined the potential effects of climate change on molds (Beggs 2004). Reviews on the consequences of climate change in human diseases highlight the importance of assessing the dynamics of airborne pollen and spores over time (D'Amato and Cecchi 2008; Shea et al. 2008; Reid and Gamble 2009; Ziska and Beggs 2012; Barnes et al. 2013). Studies made in Derby and Cardiff (UK) show that *Aspergillus/Penicillium* had an increasing trend, while *Alternaria* showed both increasing and decreasing trends (Corden and Millington 2001; Corden et al. 2003; Millington and Corden 2005). On the other hand, Damialis et al. (2015a, b) analyze the trends of 14 spore types in Thessaloniki (Greece) and find that Ascospores are the only taxon showing a positive percentage of change together with *Alternaria* that seems to slightly increase their yearly spore index over time. *Agrocybe*, *Botrytis*, *Cladosporium*, *Nigrospora* and the aggregate of the 14 spore types are the only taxa showing significant trends.

Knowing that several studies have demonstrated that changes in the meteorological conditions affect the airborne pollen concentration (Rasmussen 2002; Breton et al. 2006; García-Mozo et al. 2006; Stach et al. 2007; Fernández-Llamazares et al. 2014), we have decided to analyze the annual indices of 20 airborne fungal spore taxa over a 19-year period (1995–2013) and throughout the territory of Catalonia (NE Spain), represented by 8 localities lying in 4 phytoclimates. Statistical analyses of these time series were performed with the aims of:

1. Determine whether there is a temporal trend in the annual fungal spore index (AFSI) of the 20 taxa in the 4 phytoclimates represented by the 8 aerobiological stations of Catalonia by means of 2 nonparametric tests: Mann–Kendall (MK) and Spearman's Rho (SR).
2. Evaluate and compare the performance of the MK and SR tests to detect monotonic trends by means of the power of the tests, which is the probability of correctly detecting a monotonic trend.
3. Analyze the proportional annual change per year (PAC year⁻¹) introduced by Ziello et al. (2012) and Fernández-Llamazares et al. (2014), and study if it is significantly different from zero, whether positive or negative, by using 3 different grouping criteria: per phytoclimate, per station and per spore taxon.

2 Materials and methods

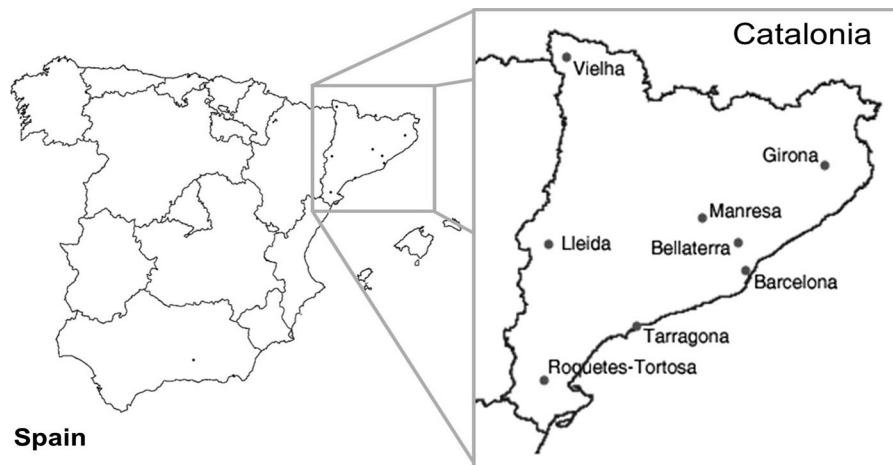
2.1 Study area

The area under study is Catalonia (NE Spain, western Mediterranean basin). Although the climate in the region is mainly Mediterranean, some areas show a continental or even Atlantic influence (Allue Andrade 1990); see Table 1 and Fig. 1 with the characteristics and location of the 8 Catalan stations. Three of the stations are considered as having an urban environment (Barcelona, Girona and Tarragona), 2 stations are closer to rural than to urban conditions (Lleida and Vielha), and 3 are urban/rural stations (Bellaterra, Manresa and Roquetes-Tortosa). Vielha, the northern station, is placed in a Pyrenean valley open to the French territory and shows the coldest and rainiest phytoclimate (Fresh-Continental Oriental-Humid phytoclimate, FCOH); Bellaterra, Girona and Manresa are described as fresh and humid and corresponding to the Fresh-Continental Oriental-Semihumid phytoclimate (FCOSH); Lleida, at a similar latitude but inland, has more extreme conditions, being its phytoclimate Fresh-Transitional-Semiarid (FTrSa); finally, Barcelona, Tarragona and Roquetes-Tortosa, in the littoral and in the middle and southern part of Catalonia, have hotter and dryer conditions than the previous stations and correspond to the Fresh-Tethyc-Semiarid phytoclimate (FTeSa).

Table 1 Sampling stations, corresponding phytoclimates and main geographical and meteorological characteristics as defined by Allue Andrade (1990) (during the study period)

Phytoclimate (code)	Station period	Environment	Coordinates	Altitude m.a.s.l.	% Days with data (min–max)	T _{mean} °C (Study period)	P _{mm} (Study period)
Fresh-Continental Oriental-Humid (FCOH)	Vielha	Rural	42°42'08"N	997	88	9.9	899.0
	2004–2013		00°47'50"E		(82–100)	(9.3)	(903.9)
Fresh-Continental Oriental-Semihumid (FCOSh)	Bellaterra	Rural/Urban	41°30'02"	245	97	15.2	594.0
	1995–2013		02°06'28"E		(94–100)	(15.2)	(536.7)
	Girona	Urban	41°59'03"N	80	92	15.0	740.0
	2000–2013		02°49'23"E		(82–100)	(15.6)	(658.1)
	Manresa	Rural/Urban	41°43'12"N	291	96	13.6	619.0
Fresh-Tethyc-Semi-arid (FTeSa)	2000–2013		01°50'23"E		(61–100)	(14.9)	(540.1)
	Barcelona	Urban	41°23'37"N	67	94	16.4	593.0
	1995–2013		02°09'53"E		(95–100)	(15.1)	(585.1)
	Tarragona	Urban	41°07'12"N	44	94	15.8	478.0
	2000–2013		01°14'37"E		(71–100)	(15.8)	(569.7)
Fresh-Transitional-Semi-arid (FTrSa)	Roquetes-Tortosa	Rural/Urban	40°49'13"N	50	95	16.8	576.0
	2006–2013		00°29'35"E		(82–100)	(17.6)	(500.5)
	Lleida	Rural	41°37'41"N	192	91	15.1	385.0
	2006–2013		00°35'44"E		(63–98)	(14.3)	(290.3)

T_{mean} Mean annual temperature, P annual precipitation

**Fig. 1** Geographical situation of the aerobiological sampling stations

2.2 Aerobiological data

The data were extracted from the database of the Catalan Aerobiological Network (Xarxa Aero-biològica de Catalunya, XAC), and they were obtained from samples coming from Hirst traps (Hirst 1952)

and analyzed following the standard methodology proposed by the Spanish Aerobiology Network (Red Española de Aerobiología, REA) in Galán et al. (2007). The daily counts were expressed as mean daily number of fungal spores per cubic meter of air ($s\ m^{-3}$) and converted to annual fungal spore index (AFSI) by

summing up the mean daily spore concentrations of the year. The stations provided different number of yearly periods comprised between 1995 and 2013: the whole series of 19 years in the case of Barcelona and Bellaterra, 14 years (2000–2013) in Girona, Lleida, Manresa and Tarragona, 9 years (2004–2013) in Vielha and 7 years (2006–2013) in Roquetes-Tortosa. The minimum number of records of a yearly data series to be included in the analyses was 276 mean daily concentration data.

In this paper, we consider 20 fungal spore taxa: 5 Ascospore types (*Chaetomium*, *Leptosphaeria*, *Pleospora*, Venturiaceae and Xylariaceae), 5 Basidiospore types (*Agaricus*, *Agrocybe*, Coprinaceae, *Ganoderma* and Teleforaceae) and 10 Conidiospores or Anamorphic fungal types (*Alternaria*, *Arthrrium*, *Aspergillus*–*Penicillium*, *Cladosporium*, *Curvularia*, *Drechslera*–*Helminthosporium*, *Epicoccum*, *Pithomyces*, *Stemphylium* and *Torula*).

2.3 Data analysis and statistical processing

In this study, with the main aim to detect monotonic trends in the fungal spore time series, the nonparametric rank-based tests Spearman's Rho (SR) and Mann–Kendall (MK) are used, both at the 5 and 1 % significant levels. Although parametric tests for the detection of significant trends in time series are more powerful than nonparametric ones, they require data to be independent and normally distributed. The lack of normality of aerobiological data has been commented, e.g., in Fernández-Llamazares et al. (2014), Grinn-Gofroń and Strzelczak (2008a, b) and Astray et al. (2010), Scheifinger et al. (2013). Despite it, we have applied the Shapiro–Wilk test (Shapiro and Wilk 1965) to all our series confirming their non-normality. SR test (Spearman 1904) is performed by calculating the exact Rho statistic (ρ) and comparing it with the critical values (Zar 1972). In relation to the MK test (Kendall 1938; Mann 1945), when the number of studied years is $n \leq 10$, the exact p values are obtained in Gilbert (1987), while when $n > 10$, asymptotic p values can be calculated by using the normal (Gaussian) approximation of the distribution of the Mann–Kendall statistic (Kendall 1975). The Theil–Sen (TS) estimator (Theil 1950; Sen 1968) of the slope value of the trend (expressed in number of spores) is calculated when at least one of the previous tests indicates a statistically significant monotonic trend.

With the aim to compare the nonparametric MK and SR monotonic trend tests, we perform the McNemar's test (McNemar 1947), which is a nonparametric test used on nominal data, applied to 2×2 contingency tables with a dichotomous trait, with matched pairs that must be independent, to determine whether the row and column marginal frequencies are homogenous. In our setting, this test is applied to compare the dichotomous result (detected significant trend or not) with the two tests.

The third and final aim of this work is to investigate the proportional annual change per year (PAC) for each station, phytoclimate and spore taxon. We first standardize each AFSI by subtracting from the annual value the respective mean of the period and dividing by the corresponding standard deviation. Then, we calculate the slope of the linear regression of the standardized AFSI at each station with respect to time (years), and divide it by the number of years in each data series (Ziello et al. 2012; Fernández-Llamazares et al. 2014). We graphically analyze the PAC behavior by means of boxplots, grouped by phytoclimate, by station and by spore taxon. To complete this analysis, we perform the two-sided Wilcoxon–Mann–Whitney test (Wilcoxon 1945; Mann and Whitney 1947) as proposed by Ziello et al. (2012). This test, which is the nonparametric counterpart of the Student's t test for comparison of two means, was also applied by Fernández-Llamazares et al. (2014).

3 Results

Table 2 shows the AFSI for the period under study and the corresponding mean values for each phytoclimate. It is shown that the FTrSa phytoclimate (represented by Lleida) presents, with a mean yearly value of 730,247, the highest AFSI of the 20 fungal spore taxa, followed by FCOSh (average AFSI of Girona, Manresa and Bellaterra of 494,785), FTeSa (average of 307,039 for Barcelona, Tarragona and Roquetes-Tortosa) and FCOH (259,554 for Vielha). Still regarding the fungal spore production and dissemination, the inland stations (Girona, Manresa and Bellaterra in FCOSh phytoclimate) show higher values than the littoral stations (Barcelona, Tarragona and Roquetes-Tortosa in FTeSa phytoclimate). If we take into consideration the mean AFSI for all Catalan stations, the more abundant taxa are *Cladosporium*

Table 2 Summary of the mean annual fungal spore index (AFSI) of the studied taxa per station and phytoclimate

Taxon	FCOH		FCOSH		FTeSa			FTrSa			Total
	Vielha	Bellaterra	Girona	Manresa	Mean	Barcelona	Tarragona	Roquetes-Tortosa	Mean	Lleida	
<i>Agaricus</i>	2237	4755	8773	2214	5247	2312	1104	2688	2034	2872	26,953
<i>Agrocybe</i>	28,264	23,484	26,101	26,391	25,325	9852	14,173	16,633	13,553	8938	153,834
<i>Alternaria</i>	2010	11,749	13,287	22,094	15,710	9459	10,451	13,661	11,190	38,046	120,757
<i>Arthrinium</i>	218	1723	1097	2002	1607	1335	1315	1203	1284	1654	10,548
<i>Aspergillus-Penicillium</i>	3421	5241	7591	5314	6049	4991	3853	5732	4859	5253	41,396
<i>Chaetomium</i>	45	183	149	131	154	227	248	85	186	193	1261
<i>Cladosporium</i>	162,172	300,968	361,354	461,694	374,672	197,549	211,120	321,709	243,459	615,415	2,631,982
<i>Coprinaceae</i>	33,524	34,679	50,338	30,131	38,383	11,197	14,002	22,042	15,747	30,163	226,075
<i>Curvularia</i>	71	93	88	260	147	50	38	39	42	86	725
<i>Drechslera-Helminthosporium</i>	681	2292	2572	3499	2788	2225	2334	1859	2139	4638	20,099
<i>Epicoccum</i>	1258	1396	3293	1994	2228	1512	956	894	1120	4151	15,455
<i>Ganoderma</i>	16,236	3737	7476	1382	4198	1639	1565	1507	1570	1981	35,522
<i>Leptosphaeria</i>	2121	6248	6731	8508	7162	2077	4519	4160	3585	4200	38,563
<i>Pithomyces</i>	232	153	269	181	201	158	119	126	134	155	1392
<i>Pleospora</i>	875	2731	1875	4070	2892	1843	2817	3337	2665	6346	23,893
<i>Stemphylium</i>	111	961	944	1769	1224	882	767	897	848	2125	8454
<i>Teleoraceae</i>	2081	2305	4457	3510	3424	1209	1137	1196	1181	434	16,328
<i>Torula</i>	354	732	1297	1280	1103	764	777	833	798	2935	8992
<i>Venturiaceae</i>	494	269	144	121	178	143	35	88	89	37	1331
<i>Xylariaceae</i>	3149	1674	3509	1096	2093	591	543	526	553	623	11,711
Total	259,554	405,371	501,344	577,640	494,785	250,014	271,869	399,233	307,039	730,247	3,395,272

FCOH Fresh-Continental Oriental-Humid, FCOSH Fresh-Continental Oriental-Semihumid, FTeSa Fresh-Tethyc-Semiarid, FTrSa Fresh-Transitional-Semiarid

(2,631,982), Coprinaceae (226,075) and *Agrocybe* (153,834) and the less abundant are *Curvularia* (725), *Chaetomium* (1261) and Venturiaceae (1331).

Table 3 shows results corresponding to the first goal of our study, that is the statistically significant results obtained for each spore taxon and station when applying SR and MK tests to the detection of monotonic trends in the AFSI through time, as well as the TS estimation of the slope of the change. All the 20 taxa studied presented significant trends in one or more stations or phytoclimates. FCOSH presented 17 taxa with significant trends, followed by FTeSa, FTrSa and FCOH with 15, 13 and 9, respectively. Regarding the TS estimator, the maximum and minimum AFSI increasing change (65,931.9 *Cladosporium* and 3.9 Venturiaceae) occurs in FTrSa (Lleida), while the maximum and minimum decrease change in the AFSI happens in FTeSa (−374.6 *Drechslera-Helminthosporium* in Roquetes-Tortosa and −1.2 *Pithomyces* in Tarragona). *Agrocybe* is the only fungal spore taxon showing a significant trend in the AFSI in the 4 phytoclimates studied and all sampling stations, with increasing trends between 20.8 % (Vielha) and 6.8 % (Bellaterra); if expressed in number of spores per year, the stations are Vielha (5869) and Barcelona (678). Regarding the other taxa, most of them show trends of the same sign in all phytoclimates except *Alternaria* (decreasing only in FCOSH); *Pithomyces*, *Stemphylium* and *Torula* (increasing only in FTrSa); and Venturiaceae (with diverse behavior in the same phytoclimate).

Table 4 shows that *Agrocybe* has the most significant trends in the Catalan stations (87.5 % of the trends obtained significant and increasing in both SR and MK tests), followed by *Cladosporium* (87.5 % increasing with SR and 75 % with MK) and *Drechslera-Helminthosporium* (50 % decreasing with SR and 87.5 % with MK), while *Epicoccum*, *Pleospora* and Teleforaceae have the lowest percentage among that with nonzero significant trends in their series (12.5 % increasing with one of the tests, 0 % with the other), followed by *Arthrinium* (12.5 % increasing both with SR and MK) and *Leptosphaeria* (37.5 % decreasing with MK, 0 % with SR), and *Pithomyces* (12.5 % increasing and 25 % decreasing with MK, while 0 % for both trends with SR). If we consider the global mean values for the 20 taxa and the 8 stations in Catalonia, only 40 % of the stations show a trend for any spore type.

The results observed in Table 3 do not differ significantly according to whether the nonparametric test used for trend detection is MK or SR, as it may be suspected from the observation of Table 4, and indeed is confirmed by means of the McNemar's test (Table 5). As the *p* value is 0.27, our aerobiological data show that MK and SR tests are equivalent in practice.

Figure 2a, b shows the boxplots for the PAC by phytoclimate and by station, respectively, as well as the *p* values for the two-sided Wilcoxon–Mann–Whitney test. FCOH (Vielha) presents the largest and more positive proportion of change, jointly with FTrSa, while FCOSH and FTeSa (Barcelona, Tarragona and Roquetes-Tortosa) show the highest stability. Results are statistically significant for the phytoclimates represented in our study by a single station (FCOH and FTrSa, Fig. 2a) and for the localities of Vielha, Lleida and Tarragona (high significance), and Girona and Roquetes-Tortosa (Fig. 2b). Interpretation of Fig. 2c, where the results by taxa are presented, is similar and gives us outcomes that 12 fungal spores increase significantly (all the Basidiospores studied: *Agaricus*, *Agrocybe*, Coprinaceae, *Ganoderma* and Teleforaceae; 2 Ascospores: *Leptosphaeria* and Xylariaceae; and 5 Anamorphic fungi: *Alternaria*, *Aspergillus/Penicillium*, *Cladosporium*, *Epicoccum* and *Torula*). *Agrocybe* presents the highest PAC, followed by *Aspergillus-Penicillium* and *Cladosporium*. Also 2 Anamorphic fungi taxa have a significant decreasing trend (*Drechslera-Helminthosporium* and *Curvularia*), and 6 do not show a significant trend (3 Ascospores: *Chaetomium*, *Leptosphaeria* and Venturiaceae, and 3 Anamorphic fungi: *Arthrinium*, *Pithomyces* and *Stemphylium*).

4 Discussion

The airborne spore concentrations are affected by several factors, i.e., fungal physiology (reproduction and survival), meteorological data, land use, resource availability and competition (Carlile et al. 2001; Boddy et al. 2014). Taking into account the AFSI shown in Table 2, the highest values in the FTrSa phytoclimate (Lleida) are possibly due to the land use in this area, where the 49 % of the total agricultural surface of Catalonia is concentrated (Institut d'Estadística de Catalunya 2013). In this sense, Manresa

Table 3 Significant monotonic trends detected in the analyses of the AFSI per sampling station, phytoclimate and spore taxa and estimation of the magnitude of the change

Station	Taxon (No. of yearly series)	Mean AFSI spores	Spearman's Rho ^a	Mann–Kendall ^b	Theil–Sen ^c spores	Theil Sen as of mean AFSI (%)
FCOH						
Vielha	<i>Agaricus</i> (8)	2237	Inc**	Inc**	797.5	35.7
	<i>Agrocybe</i> (8)	28,264	Inc*		5868.7	20.8
	<i>Alternaria</i> (9)	2010	Inc*		233.3	11.6
	<i>Arthrinium</i> (8)	218	Inc**	Inc**	48.1	22.0
	<i>Aspergillus–Penicillium</i> (8)	3421	Inc**	Inc**	589.3	17.2
	<i>Cladosporium</i> (9)	162,172	Inc**	Inc**	27,702.6	17.1
	Coprinaceae (8)	33,524	Inc**	Inc**	3864.4	11.5
	<i>Drechs.–Helminth.</i> (8)	681	Dec**	Dec**	–125.8	–18.5
	Venturiaceae (6)	494	Inc*	Inc**	347.2	70.3
FCOSH						
Bellaterra	<i>Agrocybe</i> (18)	23,484	Inc**	Inc**	1588.3	6.8
	<i>Alternaria</i> (19)	11,749		Dec*	–49.5	–0.4
	<i>Aspergillus–Penicillium</i> (18)	5241	Inc**	Inc**	583.8	11.1
	<i>Chaetomium</i> (19)	183	Dec*	Dec**	–10.7	–5.9
	<i>Cladosporium</i> (19)	300,968	Inc**	Inc**	14,825.5	4.9
	Coprinaceae (18)	34,679	Inc**	Inc**	1797.1	5.2
	<i>Curvularia</i> (19)	93	Dec**	Dec**	–5.6	–6.0
	<i>Drechs.–Helminth.</i> (19)	2292		Dec**	–31.6	–1.4
	<i>Ganoderma</i> (18)	3737	Inc**	Inc**	387.4	10.4
	<i>Stemphylium</i> (19)	961		Dec**	–10.5	–1.1
	Venturiaceae (18)	269		Dec**	–9.8	–3.6
	Xylariaceae (19)	1674	Inc**	Inc**	149.0	8.9
Girona	<i>Agaricus</i> (14)	8773	Inc**	Inc**	1230.9	14.0
	<i>Agrocybe</i> (14)	26,101	Inc**	Inc**	3631.0	13.9
	<i>Aspergillus–Penicillium</i> (14)	7591	Inc*	Inc*	749.8	9.9
	<i>Chaetomium</i> (14)	149		Dec**	–2.5	–1.6
	<i>Cladosporium</i> (14)	361,354	Inc**	Inc**	21,835.3	6.0
	Coprinaceae (14)	50,338	Inc*	Inc*	2220.4	4.4
	<i>Curvularia</i> (13)	88	Dec*	Dec**	–8.4	–9.5
	<i>Drechs.–Helminth.</i> (14)	2572		Dec**	–133.3	–5.2
	<i>Ganoderma</i> (14)	7476	Inc**	Inc**	787.4	10.5
	<i>Leptosphaeria</i> (14)	6731		Dec**	–277.2	–4.1
	<i>Stemphylium</i> (14)	944		Dec*	–10.9	–1.2
	Xylariaceae (14)	3509	Inc*		292.4	8.3
Manresa	<i>Agaricus</i> (13)	2214	Inc*		133.2	6.0
	<i>Agrocybe</i> (13)	26,391	Inc**	Inc**	4298.8	16.3
	<i>Cladosporium</i> (14)	461,694	Inc*		15,098.2	3.3
	<i>Curvularia</i> (13)	260	Dec**	Dec**	–43.3	–16.6
	<i>Drechs.–Helminth.</i> (13)	3499		Dec**	–297.2	–8.5
	<i>Ganoderma</i> (13)	1382	Inc*	Inc*	94.7	6.9
	<i>Leptosphaeria</i> (13)	8508		Dec**	–247.6	–2.9
	<i>Pithomyces</i> (14)	181		Dec**	–4.2	–2.3
	<i>Stemphylium</i> (13)	1769		Dec**	–144.3	–8.2
	Teleforaceae (13)	3510		Inc*	251.7	7.2
	<i>Torula</i> (13)	1280		Dec**	–25.8	–2.0
	Venturiaceae (13)	121	Inc*		14.7	12.1

Table 3 continued

Station	Taxon (No. of yearly series)	Mean AFSI spores	Spearman's Rho ^a	Mann–Kendall ^b	Theil–Sen ^c spores	Theil Sen as of mean AFSI (%)
FTeSa						
Barcelona	<i>Agrocybe</i> (17)	9852	Inc**	Inc**	678.3	6.9
	<i>Aspergillus–Penicillium</i> (17)	4991	Inc*		363.9	7.3
	<i>Chaetomium</i> (19)	227		Dec**	−8.6	−3.8
	<i>Cladosporium</i> (19)	197,549	Inc**	Inc*	7266.9	3.7
	<i>Curvularia</i> (17)	50	Dec**	Dec**	−3.7	−7.4
	<i>Leptosphaeria</i> (19)	2077		Dec**	−43.5	−2.1
	<i>Stemphylium</i> (19)	882		Dec**	−14.0	−1.6
	Venturiaceae (15)	143		Dec**	−15.9	−11.1
	Xylariaceae (19)	591	Inc**	Inc**	42.4	7.2
Roquetes–Tortosa	<i>Agrocybe</i> (8)	16,633		Inc*	4093.6	24.6
	<i>Drechs.–Helminth.</i> (8)	1859	Dec**	Dec**	−374.6	−20.1
	<i>Ganoderma</i> (8)	1507	Inc*		174.1	11.6
	<i>Torula</i> (8)	853	Dec*		−80.4	−9.4
Tarragona	<i>Agaricus</i> (13)	1104	Inc*		129.5	11.7
	<i>Agrocybe</i> (13)	14,173	Inc**	Inc**	1251.0	8.8
	<i>Alternaria</i> (13)	10,451	Inc*	Inc*	492.0	4.7
	<i>Aspergillus–Penicillium</i> (13)	3853	Inc*		607.9	15.8
	<i>Cladosporium</i> (13)	211,120	Inc**	Inc**	19,336.9	9.2
	<i>Curvularia</i> (12)	38	Dec*	Dec**	−3.5	−9.2
	<i>Drechs.–Helminth.</i> (13)	2334	Dec*	Dec**	−182.5	−7.8
	<i>Ganoderma</i> (13)	1565	Inc*	Inc*	121.2	7.7
	<i>Pithomyces</i> (14)	119		Dec*	−1.2	−1.0
	Venturiaceae (11)	35	Inc**	Inc*	5.6	16.0
FTrSa						
Lleida	<i>Agaricus</i> (13)	2872	Inc**	Inc**	415.8	14.5
	<i>Agrocybe</i> (13)	8938	Inc**	Inc**	1241.8	13.9
	<i>Alternaria</i> (14)	38,046	Inc**	Inc**	3172.7	8.3
	<i>Aspergillus–Penicillium</i> (13)	5253	Inc**	Inc**	515.2	9.8
	<i>Cladosporium</i> (14)	615,415	Inc**	Inc**	65,931.9	10.7
	Coprinaceae (13)	30,163	Inc**	Inc**	1928.4	6.4
	<i>Drechs.–Helminth.</i> (13)	4638	Dec*	Dec**	−344.6	−7.4
	<i>Epicoccum</i> (13)	4151	Inc*		216.1	5.2
	<i>Pithomyces</i> (13)	155		Inc*	9.8	6.3
	<i>Pleospora</i> (13)	6346	Inc*		395.0	6.2
	<i>Stemphylium</i> (13)	2125	Inc**	Inc**	84.8	4.0
	<i>Torula</i> (13)	2935	Inc*	Inc*	153.1	5.2
	Venturiaceae (12)	37	Inc**		3.9	10.6

Inc Increasing, Dec Decreasing, Mean AFSI annual fungal spore index average of the yearly series considered expressed in Spores, FCOH Fresh-Continental Oriental-Humid, FCOSH Fresh-Continental Oriental-Semihumid, FTeSa Fresh-Tethyc-Semiarid, FTrSa Fresh-Transitional-Semiarid

* Significance at 5 %; ** Significance at 1 %

^a Critical values (Zar 1972)

^b Mann–Kendall test, when $n \leq 10$: p values from Gilbert (1987); $n > 10$: p values from standardized Mann–Kendall statistic

^c Theil–Sen estimator of the AFSI change (spores) per year calculated when any of the two statistical tests shows a significant monotonic trend

Table 4 Distribution (in percentages) of the trends for each taxon and test considering the 8 stations studied

Taxon	Test	Nonsignificant trends (%)	Significant trends	
			Increasing (%)	Decreasing (%)
<i>Agaricus</i>	Spearman's Rho	37.5	62.5	0.0
	Mann–Kendall	62.5	37.5	0.0
<i>Agrocybe</i>	Spearman's Rho	12.5	87.5	0.0
	Mann–Kendall	12.5	87.5	0.0
<i>Alternaria</i>	Spearman's Rho	62.5	37.5	0.0
	Mann–Kendall	62.5	25.0	12.5
<i>Arthrinium</i>	Spearman's Rho	87.5	12.5	0.0
	Mann–Kendall	87.5	12.5	0.0
<i>Aspergillus–Penicillium</i>	Spearman's Rho	25.0	75.0	0.0
	Mann–Kendall	50.0	50.0	0.0
<i>Chaetomium</i>	Spearman's Rho	87.5	0.0	12.5
	Mann–Kendall	62.5	0.0	37.5
<i>Cladosporium</i>	Spearman's Rho	12.5	87.5	0.0
	Mann–Kendall	25.0	75.0	0.0
Coprinaceae	Spearman's Rho	50.0	50.0	0.0
	Mann–Kendall	50.0	50.0	0.0
<i>Curvularia</i>	Spearman's Rho	37.5	0.0	62.5
	Mann–Kendall	37.5	0.0	62.5
<i>Drechslera–Helminthosporium</i>	Spearman's Rho	50.0	0.0	50.0
	Mann–Kendall	12.5	0.0	87.5
<i>Epicoccum</i>	Spearman's Rho	87.5	12.5	0.0
	Mann–Kendall	100.0	0.0	0.0
<i>Ganoderma</i>	Spearman's Rho	37.5	62.5	0.0
	Mann–Kendall	50.0	50.0	0.0
<i>Leptosphaeria</i>	Spearman's Rho	100.0	0.0	0.0
	Mann–Kendall	62.5	0.0	37.5
<i>Pithomyces</i>	Spearman's Rho	100.0	0.0	0.0
	Mann–Kendall	62.5	12.5	25.0
<i>Pleospora</i>	Spearman's Rho	87.5	12.5	0.0
	Mann–Kendall	100.0	0.0	0.0
<i>Stemphylium</i>	Spearman's Rho	87.5	12.5	0.0
	Mann–Kendall	37.5	12.5	50.0
Teleforaceae	Spearman's Rho	100.0	0.0	0.0
	Mann–Kendall	87.5	12.5	0.0
<i>Torula</i>	Spearman's Rho	75.0	12.5	12.5
	Mann–Kendall	75.0	12.5	12.5
Venturiaceae	Spearman's Rho	50.0	50.0	0.0
	Mann–Kendall	50.0	25.0	25.0
Xylariaceae	Spearman's Rho	62.5	37.5	0.0
	Mann–Kendall	75.0	25.0	0.0
Mean	Spearman's Rho	62.5	30.6	6.9
	Mann–Kendall	58.1	24.4	17.5
Global Mean		60.3	27.5	12.2

Table 5 Comparison between Mann–Kendall (MK) and Spearman's Rho (SR) tests for monotonic trend detection

	Mann–Kendall test	
	Significant trends	Nonsignificant trends
Spearman's Rho test		
Significant trends	46	14
Nonsignificant trends	21	79

The McNemar's test is applied to the 2×2 contingency table that tabulates the outcomes of the two tests for the monotonic trend detection (MK and SR), on the sample of $n = 160$ items (20 fungal spore taxa $\times$ 8 stations)

As for the McNemar's test, the value of the statistic (with the continuity correction) is $\chi^2 = 1.21$. Since $14 + 21 = 35 > 25$, the one-sided p value is obtained from a Chi-square distribution with 1 degree of freedom, which is the approximating distribution. That is, p value = $0.27 > 0.05$. Therefore, we cannot assess that there is a significant difference between MK and SR tests from our data

and Roquetes-Tortosa, sharing urban/rural environments, show also the higher AFSI in their phytoclimate. Oliveira et al. (2010) obtained also higher spore levels in rural than in urban areas in Portugal. The higher AFSI shown by rural environments could be due to the continued growth of plants in the fields. Plants are forced to grow rapidly, and they are usually replaced along the year by other species. In these conditions, fungi can be more active than in natural conditions. Table 2 shows also that inland urban stations (Girona) show higher AFSI than those in the littoral (Barcelona, Tarragona). A possible explanation to that could be the difference in the vegetation cover in the surroundings of the sampling sites.

On the other hand, the lowest AFSI in Table 2 corresponds to Vielha (FCOH phytoclimate), where the mean annual temperature is less than 10°C and could affect the sporulation. Hasnain (1993), Hjelmroos (1993), Kurkela (1997), Reid and Gamble (2009) and Rúa-Giraldo (2013) found the temperature to be an important factor directly related to the increase in the airborne spore counts. Also shown in Table 2, *Cladosporium* is the most abundant taxon in all the studied sites, followed by Coprinaceae (except in Lleida where *Alternaria* takes the second place) and *Agrocybe*. These results are similar to those reported by Spieksma et al. (1995), Li and Kendrick (1995), Herrero et al. (2006), Oliveira et al. (2009b, 2010), Mallo et al. (2011) and Recio et al. (2012).

Regarding the significant monotonic trends detected by using the SR and MK tests (Tables 3), our study shows that in 57.5 % of the cases both tests show the same trend, while in 16.3 % of the cases only SP show significance (mostly increasing) and in 26.3 % only MK (mostly decreasing). The McNemar's test (Table 5) clarifies that despite the differences observed in the not concordant cases, both tests are equivalent in practice as previously stated by Yue et al. (2002), Shadmani et al. (2012), Fernández-Llamazares et al. (2014) and Ahmad et al. (2015).

The study of the trends of 20 taxa in 8 stations in Catalonia shows a significant increasing trend in 60 % (12) of the fungal spore taxa, a significant decreasing trend just in 10 % (2) and no trend in the remaining 30 % (6) of the spore types (Table 3, Fig. 2c). If we compare these results to those shown by Damialis et al. (2015a, b), who obtained a negative tendency in 86 % (12) of the fungal spores studied in Thessaloniki (Greece), there is agreement in the decreasing trends of *Drechslera-Helminthosporium*, *Leptosphaeria* and *Stemphylium* and disagreement for the taxa *Agrocybe*, *Cladosporium*, *Epicoccum*, *Pleospora* and *Torula* (increasing in our case). It is not easy to interpret the important differences in the results from Damialis et al. (2015a, b) and ours, as all the localities studied share Mediterranean climate. Hypothesis to be tested could be the lower precipitation values in Thessaloniki than in Catalan stations (excepted Lleida) and the vegetation type and degree of arable lands in the surroundings.

Alternaria, an important taxon at both the human and plant health level, shows a significant increasing trend in three of the Catalan localities (Vielha, Tarragona and Lleida), while it is slightly decreasing in one (Bellaterra). In Thessaloniki (Damialis et al. 2015a, b) *Alternaria* showed a very slightly positive trend. *Alternaria* was the object of an study in Derby and Cardiff (Corden and Millington 2001; Corden et al. 2003) with the conclusion that the abundance of arable lands around Derby could explain the increasing trend as well as the proximity to the sea could be the reason for the decreasing trend in the littoral city of Cardiff. This explanation is not valid for the territory under study in this paper, where the reason to the diminution of the *Alternaria* spores could be the growing urbanization of the area during the last decades and the consequent loss of arable and abandoned fields. On the contrary, our results show

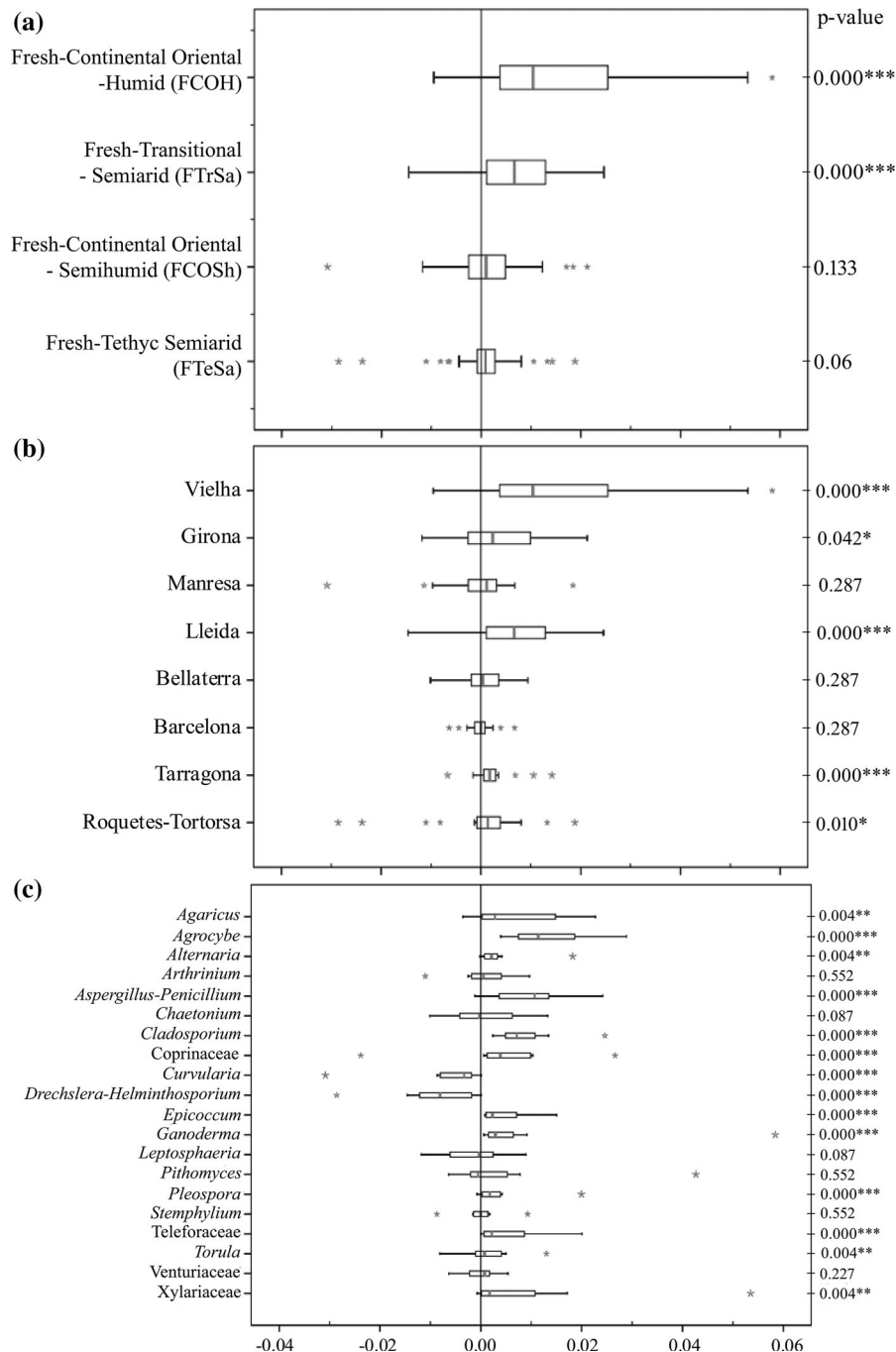


Fig. 2 Boxplots of the proportional annual change per year (PAC year⁻¹) in the mean AFSI per **a** phytoclimate, **b** sampling station and **c** fungal spore taxa. *p* value of the one-side

Wilcoxon–Mann–Whitney test. Significant difference from zero; ****p* value <0.001; ***p* value <0.01; **p* value <0.05

an increasing significant trend in *Aspergillus-Penicillium* that does not agree with previous studies (Millington and Corden 2005).

The existence of trends in the AFSI studied could also be related to the change in the meteorological patterns observed in the last decades and known as

climate change. The climate change studies in Catalonia (Equip de Canvi Climàtic 2013) noted that the mean and maximum temperatures during the period 1950–2013 increased significantly (0.22 and 0.27 °C per decade, respectively), while the precipitation suffered a slight nonsignificant decrease (−1.5 % per decade). Vielha (FCOH) is a mountain station with a low annual mean temperature (less than 10 °C) that presents the highest AFSI increasing trend, likely due to the effect of climate change on the increase in temperature and of this increase in a possible stimulation of the fungal sporulation. This process could make fungi develop better. Otherwise, the stations in the South of Catalonia (FTeSA and FCOSh), with average temperature between 15.1 and 17.6 °C, present low trends in AFSI magnitude of change, presumably due to an increase in temperature that could limit the sporulation.

The relationship between changes in temperature and sporulation has been recently demonstrated by Damialis et al. (2015a, b), where an exponential decreasing in the spore production was observed jointly with an increase in the temperature. Moreover, Carlile et al. (2001) found that the range of temperatures at which fungi tend to sporulate is narrower than the range that allows their growth and that the optimum temperature for sporulation is often lower than the one for growing. If this is so, an increase in temperature could allow fungal growth but could affect the sporulation, and always depending on the temperature range, because as seen changes can be in one sense or just the contrary.

In concordance to the above and as shown in Table 1, temperatures during the period under study were higher and precipitations were lower than the ones characterizing the phytoclimates in Allue Andrade (1990). The proportion of change shown in Fig. 2 and Table 3 could also totally or in part be the reaction of the fungal taxa to the changing meteorological conditions of the period under study, and the AFSI yearly proportion of change obtained could also inform about possible changes in fungal reproduction capacity and biodiversity in the future. Regarding the environmental conditions of the stations under study, the more rural the site (Lleida, Manresa), the highest the AFSI, while altitude (Vielha) and the size of the urban area (Barcelona) seem to be factors for decreasing the presence of spores. The localities

studied representative for the conditions of rurality (Lleida) and altitude (Vielha) are the ones showing the higher significant PAC, while Barcelona, the biggest city studied, shows no PAC.

This is a first study in Catalonia (NE Spain) on the measurement of the change of fungal spore production and dissemination over time. The lack of studies in this sense makes difficult the interpretation of the results. More research is needed to progress in the knowledge of airborne fungi spores behavior and the effect of the changing meteorological patterns on them.

5 Conclusions

The diversity of characteristics of the sites studied brings the opportunity to evaluate the variability of the fungal values and the magnitude of their change across the study period as depending on the intensity of the land use (urbanization versus agriculture) and the distance to the sea (inland versus littoral), but the effect of the change of the meteorological patterns in the recent years is not negligible. The increasing temperatures and precipitation instability established as effects of the climate change in Catalonia in the last 50 years could be stimulating the sporulation in mountain areas (Vielha) and affecting it in the southern Catalan littoral (Roquetes-Tortosa), thus affecting spore counts.

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References

- Ahmad, I., Tang, D., Wang, T. F., Wang, M., & Wagan, B. (2015). Precipitation trends over time using Man–Kendall and Spearman's rho tests in Swat River Basin, Pakistan. *Advances in Meteorology*, doi:10.1155/2015/431860.
- Allue Andrade, J. L. (1990). *Phytoclimatic atlas of Spain Taxonomies*. Madrid: INIA.
- Astray, G., Rodríguez-Rajo, F. J., Ferreiro-Lage, J. A., Fernández-González, M., Jato, V., & Mejuto, J. C. (2010). The use of artificial neural networks to forecast biological atmospheric allergens or pathogens only as *Alternaria* spores. *Journal of Environmental Monitoring*, 12, 2145–2152. doi:10.1039/C0EM00248H.
- Barnes, C. S., Alexis, N. E., Bernstein, J. A., Cohn, J. R., Demain, J. G., Horner, E., et al. (2013). Climate change and our environment: The effect on respiratory and allergic disease. *The Journal of Allergy and Clinical Immunology: In Practice*, 1, 137–141. doi:10.1016/j.jaip.2012.07.002.
- Beggs, P. J. (2004). Impacts of climate change on aeroallergens: Past and future. *Clinical and Experimental Allergy*, 34, 1507–1513. doi:10.1111/j.1365-2222.2004.02061.x.
- Blanco, C., Santos, B., & los de Romero, F. (2006). Relationship between concentrations of botrytis cinerea conidia in air, environmental conditions, and the incidence of grey mould in strawberry flowers and fruits. *European Journal of Plant Pathology*, 114, 415–425. doi:10.1007/s10658-006-0007-3.
- Boddy, L., Büntgen, U., Egli, S., Gange, A. C., Heegaard, E., Kirk, P. M., et al. (2014). Climate variation effects on fungal fruiting. *Fungal Ecology*, 10, 20–33. doi:10.1016/j.funeco.2013.10.006.
- Breton, M.-C., Garneau, M., Fortier, I., Guay, F., & Louis, J. (2006). Relationship between climate, pollen concentrations of Ambrosia and medical consultations for allergic rhinitis in Montreal, 1994–2002. *Science of the Total Environment*, 370, 39–50. doi:10.1016/j.scitotenv.2006.05.022.
- Burch, M., & Levetin, E. (2002). Effects of meteorological conditions on spore plumes. *International Journal of Biometeorology*, 46, 107–117.
- Carlile, M. J., Watkinson, S. C., Gooday, G. W. (2001). Spores, dormancy and dispersal. In M. J. C. C. W. W. Gooday (Ed.), *The fungi* (2nd edn, pp. 185–243). London: Academic Press.
- Corden, J. M., & Millington, W. M. (2001). The long-term trends and seasonal variation of the aeroallergen *Alternaria* in Derby, UK. *Aerobiologia*, 17, 127–136. doi:10.1023/A:1010876917512.
- Corden, J. M., Millington, W. M., & Mullins, J. (2003). Long-term trends and regional variation in the aeroallergen *Alternaria* in Cardiff and Derby UK—Are differences in climate and cereal production having an effect? *Aerobiologia*, 19, 191–199. doi:10.1023/B:AERO.0000006529.51252.2f.
- D'Amato, G., & Cecchi, L. (2008). Effects of climate change on environmental factors in respiratory allergic diseases. *Clinical and Experimental Allergy*, 38, 1264–1274. doi:10.1111/j.1365-2222.2008.03033.x.
- Damialis, A., Mohammad, A. B., Halley, J. M., & Gange, A. C. (2015a). Fungi in a changing world: growth rates will be elevated, but spore production may decrease in future climates. *International Journal of Biometeorology*, 59, 1157–1167. doi:10.1007/s00484-014-0927-0.
- Damialis, A., Vokou, D., Gioulekas, D., & Halley, J. M. (2015b). Long-term trends in airborne fungal-spore concentrations: a comparison with pollen. *Fungal Ecology*, 13, 150–156. doi:10.1016/j.funeco.2014.09.010.
- De Linares, C., Belmonte, J., Canela, M., de la Guardia, C. D., Alba-Sanchez, F., Sabariego, S., & Alonso-Pérez, S. (2010). Dispersal patterns of *Alternaria* conidia in Spain. *Agricultural and Forest Meteorology*, 150, 1491–1500. doi:10.1016/j.agrformet.2010.07.004.
- Equip de Canvi Climàtic. (2013). Butlletí anual d'indicadors climàtics [Informe anual No. 7 (any 2013)] [Informe anual No. 7 (año 2013)], Butlletí anual d'indicadors climàtics. Servei meteorològic de Catalunya, Generalitat de Catalunya, Departament de Territori i Sostenibilitat, Catalunya.
- Escuredo, O., Seijo, M. C., Fernández-González, M., & Iglesias, I. (2011). Effects of meteorological factors on the levels of *Alternaria* spores on a potato crop. *International Journal of Biometeorology*, 55, 243–252. doi:10.1007/s00484-010-0330-4.
- Fernández-González, M., Rodríguez-Rajo, F. J., Jato, V., Aira, M. J., Ribeiro, H., Oliveira, M., & Abreu, I. (2012). Forecasting ARIMA models for atmospheric vineyard pathogens in Galicia and Northern Portugal: Botrytis cinerea spores. *Annals of Agricultural and Environmental Medicine*, 19(2), 255–262.
- Fernández-Llamazares, Á., Belmonte, J., Delgado, R., & De Linares, C. (2014). A statistical approach to bioclimatic trend detection in the airborne pollen records of Catalonia (NE Spain). *International Journal of Biometeorology*, 58, 371–382. doi:10.1007/s00484-013-0632-4.
- Galán, C., Cariñanos, P. P., Alcázar, P., & Dominguez, E. (2007). *Manual de calidad y gestión de la Red Española de Aerobiología*. Córdoba: Universidad de Córdoba.
- García-Mozo, H., Galán, C., Jato, V., Belmonte, J., de la Guardia, C. D., Fernández, D. C., et al. (2006). Quercus pollen season dynamics in the Iberian Peninsula: response to meteorological parameters and possible consequences of climate change. *Annals of Agricultural and Environmental Medicine*, 13, 209.
- Gilbert, R. O. (1987). *Statistical methods for environmental pollution monitoring*. Hoboken: Wiley.
- Grinn-Gofroń, A., & Strzelczak, A. (2008a). Artificial neural network models of relationships between Cladosporium spores and meteorological factors in Szczecin (Poland). *Grana*, 47, 305–315. doi:10.1080/00173130802513784.
- Grinn-Gofroń, A., & Strzelczak, A. (2008b). Artificial neural network models of relationships between *Alternaria* spores and meteorological factors in Szczecin (Poland). *International Journal of Biometeorology*, 52, 859–868. doi:10.1007/s00484-008-0182-3.
- Grinn-Gofroń, A., & Strzelczak, A. (2011). The effects of meteorological factors on the occurrence of Ganoderma sp. spores in the air. *International Journal of Biometeorology*, 55, 235–241. doi:10.1007/s00484-010-0329-x.
- Hasnain, S. M. (1993). Influence of meteorological factors on the air spora. *Grana*, 32, 184–188.
- Herrero, A. D., Ruiz, S. S., Bustillo, M. G., & Morales, P. C. (2006). Study of airborne fungal spores in Madrid, Spain.

- Aerobiologia*, 22, 133–140. doi:[10.1007/s10453-006-9025-z](https://doi.org/10.1007/s10453-006-9025-z).
- Hirst, J. M. (1952). An automatic volumetric spore trap. *Annals of Applied Biology*, 39, 257–265. doi:[10.1111/j.1744-7348.1952.tb00904.x](https://doi.org/10.1111/j.1744-7348.1952.tb00904.x).
- Hjelmroos, M. (1993). Relationship between airborne fungal spore presence and weather variables: Cladosporium and Alternaria. *Grana*, 32, 40–47. doi:[10.1080/00173139309436418](https://doi.org/10.1080/00173139309436418).
- Institut d'Estadística de Catalunya. (2013). Superfície agrícola. 2013 Principales productos. Provincias [WWW Document]. idescat. <http://www.idescat.cat/pub/?id=aec&n=445&lang=es> (Accessed 19 May, 2015).
- Kendall, M. G. (1938). A new measure of rank correlation. *Biometrika*, 30(1/2), 81–93. doi:[10.2307/2332226](https://doi.org/10.2307/2332226).
- Kendall, M. G. (1975). *Rank correlation methods*. New York: Hafner.
- Kurkela, T. (1997). The number of Cladosporium conidia in the air in different weather conditions. *Grana*, 36, 54–61. doi:[10.1080/00173139709362591](https://doi.org/10.1080/00173139709362591).
- Lacey, J. (1981). The aerobiology of conidial fungi. *Biology of Conidial Fungi*, 1, 373–416.
- Leyronas, C., & Nicot, P. C. (2013). Monitoring viable airborne inoculum of Botrytis cinerea in the South-East of France over 3 years: Relation with climatic parameters and the origin of air masses. *Aerobiologia*, 29, 291–299. doi:[10.1007/s10453-012-9280-0](https://doi.org/10.1007/s10453-012-9280-0).
- Li, D.-W., & Kendrick, B. (1995). A year-round outdoor Aeromycological study in Waterloo, Ontario, Canada. *Grana*, 34, 199–207. doi:[10.1080/00173139509429043](https://doi.org/10.1080/00173139509429043).
- Mallo, A. C., Nitiu, D. S., & Sambeth, M. C. G. (2011). Airborne fungal spore content in the atmosphere of the city of La Plata, Argentina. *Aerobiologia*, 27, 77–84. doi:[10.1007/s10453-010-9172-0](https://doi.org/10.1007/s10453-010-9172-0).
- Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica: Journal of the Econometric Society*, 13(3), 245–259. doi:[10.2307/1907187](https://doi.org/10.2307/1907187).
- Mann, H. B., & Whitney, D. R. (1947). On a test of whether one of two random variables is stochastically larger than the other. *The Annals of Mathematical Statistics*, 18(1), 50–60.
- McNemar, Q. (1947). Note on the sampling error of the difference between correlated proportions of percentages. *Psychometrika*, 12(2), 153–157.
- Millington, W. M., & Corden, J. M. (2005). Long term trends in outdoor Aspergillus/Penicillium spore concentrations in Derby, UK from 1970 to 2003 and a comparative study in 1994 and 1996 with the indoor air of two local houses. *Aerobiologia*, 21, 105–113. doi:[10.1007/s10453-005-4180-1](https://doi.org/10.1007/s10453-005-4180-1).
- Moral, J., De la Rosa, R., León, L., Barranco, D., Michailides, T. J., & Trapero, A. (2008). High susceptibility of olive cultivar FS-17 to *Alternaria alternata* in Southern Spain. *Plant Disease*, 92, 1252. doi:[10.1094/PDIS-92-8-1252A](https://doi.org/10.1094/PDIS-92-8-1252A).
- Oliveira, M., Guerner-Moreira, J., Mesquita, M. M., & Abreu, I. (2009a). Important phytopathogenic airborne fungal spores in a rural area: incidence of Botrytis cinerea and Oidium spp. *Annals of Agricultural and Environmental Medicine*, 16, 197–204.
- Oliveira, M., Ribeiro, H., Delgado, J. L., & Abreu, I. (2009b). The effects of meteorological factors on airborne fungal spore concentration in two areas differing in urbanisation level. *International Journal of Biometeorology*, 53, 61–73. doi:[10.1007/s00484-008-0191-2](https://doi.org/10.1007/s00484-008-0191-2).
- Oliveira, M., Ribeiro, H., Delgado, L., Fonseca, J., Gastel-Branco, M. G., & Abreu, I. (2010). Outdoor allergenic fungal spores: Comparison between an urban and a rural area in Northern Portugal. *Journal of Investigational Allergology and Clinical Immunology*, 20, 117.
- Rasmussen, A. (2002). The effects of climate change on the birch pollen season in Denmark. *Aerobiologia*, 18, 253–265. doi:[10.1023/A:1021321615254](https://doi.org/10.1023/A:1021321615254).
- Recio, M., del Trigo, M. M., Docampo, S., Melgar, M., García-Sánchez, J., Bootello, L., & Cabezero, B. (2012). Analysis of the predicting variables for daily and weekly fluctuations of two airborne fungal spores: Alternaria and Cladosporium. *International Journal of Biometeorology*, 56, 983–991. doi:[10.1007/s00484-011-0509-3](https://doi.org/10.1007/s00484-011-0509-3).
- Reid, C. E., & Gamble, J. L. (2009). Aeroallergens, allergic disease, and climate change: Impacts and adaptation. *EcoHealth*, 6, 458–470. doi:[10.1007/s10393-009-0261-x](https://doi.org/10.1007/s10393-009-0261-x).
- Rodríguez-Rajo, F. J., Jato, V., Fernández-González, M., & Aira, M. J. (2010). The use of aerobiological methods for forecasting Botrytis spore concentrations in a vineyard. *Grana*, 49, 56–65. doi:[10.1080/00173130903472393](https://doi.org/10.1080/00173130903472393).
- Rúa-Giraldo, A. L. (2013). *Aerobiología de las esporas de Pleosporales en ambientes intra y extradomiciliarios de Barcelona. Aplicación a la clínica en población alérgica (info:eu-repo/semantics/doctoralThesis)*. Barcelona: Universitat Autònoma de Barcelona.
- Scheifinger, H., Belmonte, J., Buters, J., Celenk, S., Damialis, A., & Dechamp, C. et al. (2013). Monitoring, modelling and forecasting of the pollen season. In: M. Sofiev & K.-C. Bergmann (Eds.), *Allergenic pollen* (pp. 71–126). Springer Netherlands. http://link.springer.com/chapter/10.1007/978-94-007-4881-1_4. Accessed 14 November 2014.
- Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association*, 63, 1379–1389.
- Shadmani, M., Marofi, S., & Roknian, M. (2012). Trend analysis in reference evapotranspiration using Mann–Kendall and Spearman's Rho tests in arid regions of Iran. *Water Resource Management*, 26, 211–224. doi:[10.1007/s11269-011-9913-z](https://doi.org/10.1007/s11269-011-9913-z).
- Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, 52(3/4), 591–611. doi:[10.2307/2333709](https://doi.org/10.2307/2333709).
- Shea, K. M., Truckner, R. T., Weber, R. W., & Peden, D. B. (2008). Climate change and allergic disease. *Journal of Allergy and Clinical Immunology*, 122, 443–453. doi:[10.1016/j.jaci.2008.06.032](https://doi.org/10.1016/j.jaci.2008.06.032).
- Simon-Nobbe, B., Denk, U., Rid, R., & Breitenbach, M. (2008). The spectrum of fungal allergy. *International Archives of Allergy and Immunology*, 145, 58–86.
- Spearman, C. (1904). “General Intelligence”, objectively determined and measured. *American Journal of Psychology*, 15, 201–292.
- Spieksma, F. T. M., Emberlin, J. C., Hjelmroos, M., Jäger, S., & Leuschner, R. M. (1995). Atmospheric birch (Betula) pollen in Europe: Trends and fluctuations in annual quantities and the starting dates of the seasons. *Grana*, 34, 51–57. doi:[10.1080/00173139509429033](https://doi.org/10.1080/00173139509429033).

- Stach, A., García-Mozo, H., Prieto-Baena, J. C., Czarnecka-Operacz, M., Jenerowicz, D., Silny, W., & Galán, C. (2007). Prevalence of *Artemisia* species pollinosis in western Poland: Impact of climate change on aerobiological trends. *Journal of Investigational Allergology and Clinical Immunology*, 17, 39–47.
- Tao, Z., Malvick, D., Claybrooke, R., Floyd, C., Bernacchi, C. J., Spoden, G., et al. (2009). Predicting the risk of soybean rust in Minnesota based on an integrated atmospheric model. *International Journal of Biometeorology*, 53, 509–521. doi:[10.1007/s00484-009-0239-y](https://doi.org/10.1007/s00484-009-0239-y).
- Theil, H. (1950). A rank-invariant method of linear and polynomial regression analysis I, II, III. In *Proceedings of Koninklijke Nederlandse Akademie van Wetenschappen*, pp. 1397–1412.
- Wilcoxon, F. (1945). Individual comparisons by ranking methods. *Biometrics Bulletin*, 1(6), 80–83. doi:[10.2307/3001968](https://doi.org/10.2307/3001968).
- Yue, S., Pilon, P., & Cavadias, G. (2002). Power of the Mann–Kendall and Spearman’s rho tests for detecting monotonic trends in hydrological series. *Journal of Hydrology*, 259, 254–271. doi:[10.1016/S0022-1694\(01\)00594-7](https://doi.org/10.1016/S0022-1694(01)00594-7).
- Zar, J. H. (1972). Significance testing of the Spearman rank correlation coefficient. *Journal of American Statistical Association*, 67, 578–580.
- Ziello, C., Sparks, T. H., Estrella, N., Belmonte, J., Bergmann, K. C., Bucher, E., et al. (2012). Changes to airborne pollen counts across Europe. *PLoS One*, 7, e34076. doi:[10.1371/journal.pone.0034076](https://doi.org/10.1371/journal.pone.0034076).
- Ziska, L. H., & Beggs, P. J. (2012). Anthropogenic climate change and allergen exposure: The role of plant biology. *Journal of Allergy and Clinical Immunology*, 129, 27–32. doi:[10.1016/j.jaci.2011.10.032](https://doi.org/10.1016/j.jaci.2011.10.032).