



Logistic regression models for predicting daily airborne *Alternaria* and *Cladosporium* concentration levels in Catalonia (NE Spain)

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Abstract

Alternaria and *Cladosporium* are the most common airborne fungal spores responsible for health problems, as well as for crop pathologies. The study of their behavior in the air is a necessary step for establishing control and prevention measures. The aim of this paper is to develop a logistic regression model for predicting the daily concentrations of airborne *Alternaria* and *Cladosporium* fungal spores from meteorological variables. To perform the logistic regression analysis, the concentration levels are binarized using concentration thresholds. The fungal spore data have been obtained at eight aerobiological monitoring stations of the Aerobiological Network of Catalonia (NE Spain). The meteorological data used were the maximum and minimum daily temperatures and daily rainfall provided by the meteorological services. The relationship between the meteorological variables and the fungal spore levels has been modeled by means of logistic regression equations, using data from the period 1995–2012. Values from years 2013–2014 were used for validation. In the case of *Alternaria*, three equations for predicting the presence and the exceedance of the thresholds 10 and 30 spores/m³ have been established. For *Cladosporium*, four equations for the thresholds 200, 500, 1000, and 1500 spores/m³ have been established. The temperature and cumulative rainfall in the last 3 days showed a positive correlation with airborne fungal spore levels, while the rain on the same day had a negative correlation. Sensitivity and specificity were calculated to measure the predictive power of the model, showing a reasonable percentage of correct predictions (ranging from 48 to 99%). The simple equations proposed allow us to forecast the levels of fungal spores that will be in the air the next day, using only the maximum and minimum temperatures and rainfall values provided by weather forecasting services.

Keywords Fungal spore dispersal patterns · Fungal spore daily concentration levels · Prediction model · Threshold

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Introduction

Nowadays, atmospheric biological particles are recognized as a problem for human, animal, and plant health and there is a growing interest to study their presence and distribution patterns. Due to the reproduction of plant and fungal organisms, the production, release, and transport of pollen and spores in the air may contribute to problems in humans, as well as in crops. *Alternaria* and *Cladosporium* are ubiquitous saprophytic fungi and opportunistic pathogens that disperse huge amounts of asexual spores (conidia) into the atmosphere (Recio et al. 2012) and are considered the most important airborne fungi (Reyes et al. 2009; Grinn-Gofroñ and Strzelczak 2013; Vélez-Pereira et al. 2016).

Recent studies show that in the industrialized world, 25% of the population is affected by atopic allergies, and allergy to molds constitutes 25–30% of all allergic asthma cases (Kurup et al. 2002). *Alternaria* and *Cladosporium* are important

fungal contaminants in many parts of the world, due to their allergic and infecting characters. *Alternaria* and *Cladosporium* account for 20% of the patients visiting an allergological center (D'Amato et al. 1997). In Spain, Ojeda et al. (2018) reported that in a group of 2914 adult patients throughout Spain with 5-year history of rhinoconjunctivitis, the etiology was allergic in 79.3% of them; molds were involved in 0.9% of cases and *Alternaria* was a relevant allergen in 5.8% of the patients with allergic rhinitis. A fraction of 21.2% (618) of the patients had bronchial asthma, which was caused by molds in 10.1% of cases. The study Alergológica 2015 (Sociedad Española de Alergología e Inmunología Clínica 2017) encountered 8.6% patients sensitized to *Alternaria alternata* and 0.3% to species of *Cladosporium* and that children were more affected by mold allergy (11.1%) than adults (4.3%). In Catalonia (NE Spain), the sensitivity to *Alternaria* was detected in 18.3% of the patients visiting the allergological centers (Bartra et al. 2009) and Alergológica 2015 (Sociedad Española de Alergología e Inmunología Clínica 2017) obtained that asthmatic patients from Catalonia were sensitized to *Alternaria alternata* in 17% of cases. Moreover, *Alternaria* spores have also been recognized as producers of toxic secondary metabolites involved in osteomyelitis, pulmonary and cutaneous infections, keratomycosis in humans (Gianni et al. 1997), cancer in mammals (Thomma 2003), and food allergies (Barkai-Golan 2008). Regarding *Cladosporium*, an exposure to high spore concentrations increases the bronchial ailments and is associated to chronic hypersensitivity pneumonitis and cutaneous diseases (Romano et al. 1999; Vieira et al. 2001; Gugnani et al. 2006; Qiu-Xia et al. 2008; Chiba et al. 2009; Revankar and Sutton 2010; Huyen et al. 2012).

Airborne *Alternaria* and *Cladosporium* spores have also been related to diseases in a large variety of crops (e.g., olives, small grain cereals, tobacco, cauliflower, broccoli, peppers, carrots, potatoes, wine grapes, pecan, tomato, and other fruits) and to cause serious economic impacts (Kirk et al. 2008; Logrieco et al. 2003; Latorre et al. 2011; Peteira et al. 2011; de Wit et al. 2012; Ogórek et al. 2012).

In the last few years, several attempts have been made to model the presence and concentration of airborne fungal spores based on meteorological forecasts. *Alternaria* and *Cladosporium* airborne concentrations were estimated by means of artificial neural networks (Bruno et al. 2007; Grinn-Gofroń and Strzelczak 2008, 2013; Astray et al. 2010), autoregressive integrated time series models (Damialis and Gioulekas 2006; Escuredo et al. 2011), linear regression models (Molina et al. 1998; Rodríguez-Rajo et al. 2005; Recio et al. 2012), and logistic regression models (De Linares et al. 2010).

In De Linares et al. (2010), the statistical analysis was based on a logistic regression approach (Hosmer and Lemeshow 2000), validating the method for predicting annual

levels of airborne *Alternaria* spores. Logistic regression models were used for real-time forecasting after transforming the probabilities predicted by the logistic regression equation into positive/negative predictions.

Although allergy or pathogeny thresholds have not been yet established, in the case of *Alternaria*, the suggested threshold concentrations in which spore-allergy sufferers start to show serious symptoms could be 10 spores/m³ (Wijnand 2009), 50 spores/m³ (Frankland and Davies 1965), or 100 spores/m³ (Green et al. 2006). In *Cladosporium*, this threshold could be 2000, 3000, or 4000 spores/m³ (Targonski et al. 1995; Ianovici et al. 2011; Hollins et al. 2004, respectively). However, in accordance with Green et al. (2006), the consequences of fungal exposure may not only be a function of the number and diversity of fungal particles but also depend on the degree of fungal germination and the efficiency of the local innate immune system to overcome virulence factors released by germinating fungi.

The aim of the present paper is to develop a simple model to predict the daily presence and levels of *Alternaria* and *Cladosporium* spores in the atmosphere based on daily basic meteorological variables (precipitation and temperature) that are usually available on common websites. The thresholds of concentration chosen to establish the levels are those associated with potential effects in the atopic population of the concentrations registered in the study area. The sensitivity and specificity of a model are used as measure of the predictive power of that model. The validation of the models was done with data from years 2013 and 2014, not used to estimate the model equations.

Materials and methods

Study area

Alternaria and *Cladosporium* data were obtained at eight locations in Catalonia (North-East Spain, Fig. 1). Although there is a clear influence of the Mediterranean climate (warm winters, hot summers, and rainy episodes in autumn and spring), Catalonia is a region with a wide diversity of local flora due to a varied geomorphology and distance to the sea, and the sampling stations lie in four phytoclimatic regions (Allue Andrade 1990). Vielha, the northern station, situated in a Pyrenean valley, shows the coldest and rainiest conditions and is considered to have a Fresh-Continental Oriental-semihumid phytoclimate. Bellaterra, Girona, and Manresa can be described as fresh and humid and the corresponding phytoclimate is Fresh-Continental Oriental-semihumid. Lleida, at a similar latitude but inland, has more extreme conditions, and the phytoclimate is Fresh-Transitional-semiarid. Barcelona, Tarragona, and Roquetes-Tortosa, in the littoral, have hotter and dryer conditions (that grow to the South) than

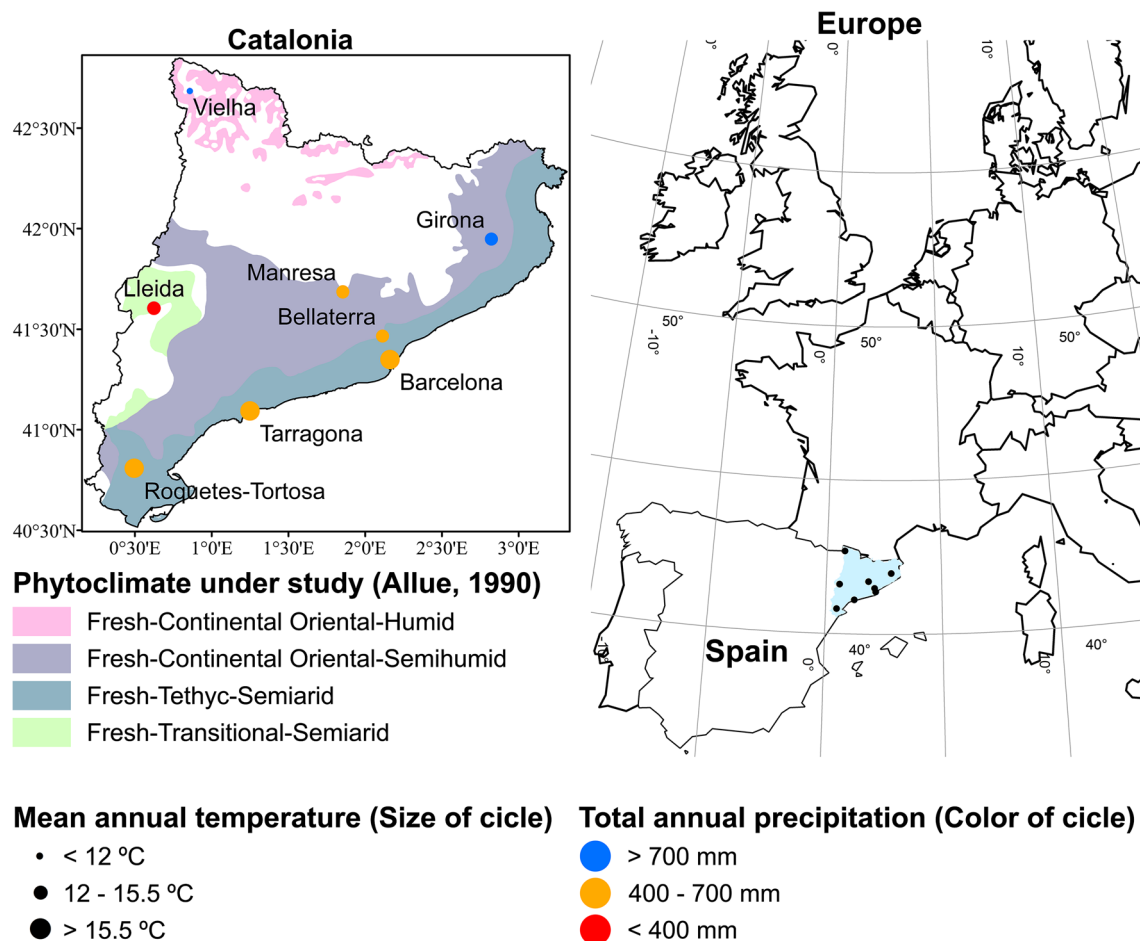


Fig. 1 Geographical situation, meteorological characteristics, and phytoclimate of the aerobiological stations of Catalonia

the previous localities and correspond to the Fresh-Tethyc-semiarid phytoclimate. Three of the stations are considered lying in an urban environment (Barcelona, Girona, and Tarragona), two in rural conditions (Lleida and Vielha), and three share urban/rural characteristics (Bellaterra, Manresa, and Roquetes-Tortosa). Table 1 and Fig. 1 show more information on the stations.

Aerobiological sampling method

The samples were obtained with Hirst traps (Hirst, 1952) and analyzed following the standard methodology proposed by the Spanish Aerobiology Network, *Red Española de Aerobiología (REA)* (Galán et al. 2007). Terminology used in this paper follows the International Association for the Aerobiology (IAA) recommendations (Galán et al. 2017). Data were expressed as the number of mean daily fungal spores per cubic meter of air (spores/m³). The stations provided series of different lengths (see Table 1), all of them between 1995 and 2012, depending on the data availability: 17 yearly series for Barcelona and Bellaterra, 12 for Girona and Manresa, 11 for Lleida and

Tarragona, 8 for Vielha, and 6 for Roquetes-Tortosa. Years 2013–2014 were used for validation. Table 2 shows the summary statistics of the *Alternaria* and *Cladosporium* data used in this study.

Although the fungal allergy and the phytopathologic character of *Alternaria* and *Cladosporium* are well recognized (Sanchez and Bush 2001; Bartra et al. 2009; Ogórek et al. 2012), there are no standard criteria for determining the thresholds of triggering allergy or impact in crops. For this reason, we have set thresholds based on the aerobiological experience of the authors. For *Alternaria* spores, three thresholds and as a consequence three logistic regression equations have been proposed [ALTE1, ALTE10, ALTE30]. Whereas the first model [ALTE1] predicts the presence of *Alternaria* spores in the atmosphere, ALTE10 informs on the *Alternaria* level exceeding 10 spores/m³ and ALTE30 on exceeding 30 spores/m³. For *Cladosporium* spores, four thresholds and the corresponding logistic regression equations have been established. CLAD200 informs whether the level of *Cladosporium* exceeds 200 spores/m³ and, with the same rule, CLAD500, CLAD1000, and CLAD1500.

Table 1 Main geographical characteristics of the aerobiological sampling stations, period under study for training of the model and for validation (in *italics*), and corresponding meteorological parameters.

Tmin, mean minimum annual temperature, *Tran* mean annual thermal oscillation, *Prec* mean annual rainfall, *Days Prec* percentage of days with rainfall

Sampling station	Geographical characteristics			Study period characteristics					
	Environment	Altitude (m.a.s.l.)	Coordinates	Training	Days with aerobiological data (%)	Meteorological parameters			
						<i>Tmin</i> (°C)	<i>Tran</i> (°C)	<i>Prec</i> (mm)	<i>Days Prec</i> (%)
Barcelona	Urban	67	41° 23' 37" N; 02° 09' 53" E	1995–2012	98.7	11.9	7.9	585.9	17.2
Bellaterra	Rural/urban	245	41° 30' 02" N; 02° 06' 28" E		98.8	9.7	11.8	539.1	17.3
Girona	Urban	80	41° 59' 03" N; 02° 49' 23" E	2000–2012	92.3	9.8	12.5	655.1	21.1
Lleida	Rural	192	41° 37' 41" N; 00° 35' 44" E		93.1	7.9	13.5	297.0	13.8
Manresa	Rural/urban	291	41° 43' 12" N; 01° 50' 23" E		98.1	8.8	12.4	547.7	16.3
Tarragona	Urban	44	41° 07' 12" N; 01° 14' 37" E		94.3	10.7	10.7	572.2	16.7
Roquetes-Tortosa	Rural/urban	50	40° 49' 13" N; 00° 29' 35" E	2006–2012	95.4	12.6	11.2	490.0	15.7
Vielha	Urban	997	42° 42' 08" N; 00° 47' 50" E	2004–2012	90.3	4.6	11.9	856.2	34.5

Meteorological data

The meteorological variables considered in this study were maximum and minimum daily temperatures (expressed in degrees Celsius) and daily rainfall (expressed in millimeters). Data were obtained from the *Agencia Estatal de Meteorología* (Barcelona until 2001; Bellaterra until 1998; and Manresa since 2000) and the *Servei Meteorològic de Catalunya* (Barcelona since 2002; Bellaterra since 1999; Girona since 2000; Lleida since 2001; Tarragona since 2000; Roquetes-Tortosa since 2006; and Vielha since 2004). Meteorological data were used in their raw form and converted to daily temperature range [Tran], calculated as the difference between the daily maximum and minimum temperatures, and accumulated precipitation on the three previous days [Precpast]. Table 1 shows the summary statistics of the meteorological variables data used in this study.

Statistical methods

The statistical analysis in this study was based on a logistic regression approach, as in De Linares et al. (2010). The study took into account dependent variables that were dummies

associated to *Alternaria* and *Cladosporium* spore concentrations and four independent variables: (a) two continuous related to temperature in degrees Celsius, *Tmin* and *Tran*; and (b) two dummies related to precipitation, *Prec* and *Precpast*. The use of discrete variables or dummy variables, taking only value 0 or value 1, simplified the analyses and reduced the difficulties of managing continuous variables. In the case of spore concentrations, dummies helped to evaluate the presence of the spores or its exceedance of a given threshold, and in the case of the precipitation, 1 was used when the value of the precipitation exceeded 0.5 mm and 0 when the value was equal or under 0.5 mm.

SPSS was used to fit seven logistic regression equations (three for *Alternaria* and four for *Cladosporium*) for each site. The values predicted by the equations were interpreted as probabilities of exceeding the corresponding spore concentration threshold. To be sure that the potential correlation between meteorological variables cannot raise a multicollinearity problem leading to the unreliability of the coefficient estimates (Petraitis et al. 1996), variation inflation factors (VIF) for all the regressors were calculated. VIF values under 10 indicate not collinearity (Myers and Myers 1990).

Table 2 Summary statistics for *Alternaria* and *Cladosporium* airborne spore data: mean Annual Fungal Spore Integral (AFSIn), mean daily and absolute daily maximum concentrations, and percentages of days withconcentrations *exceeding* the indicated thresholds during the study period for training of the model and for validation (in *italics*)

				<i>Alternaria</i>					
	Spores/m ³			% of days per interval					
Sampling station	Mean AFSIn	Mean daily concentration	Absolute daily maximum	Without	1–10	11–30	≥ 31		
Barcelona	9350/9642	26/27	470/414	17/12	27/30	27/28	28/29		
Bellaterra	12241/10779	34/30	1389/364	11/8	24/28	27/32	37/32		
Girona	13191/14867	39/43	759/846	12/11	25/29	22/21	34/39		
Lleida	37196/63084	109/210	3044/4306	3/1	9/8	19/15	62/76		
Manresa	21840/26401	61/77	1389/2030	6/3	19/17	25/23	48/57		
Tarragona	10603/10310	31/29	1506/608	10/10	26/28	30/31	29/30		
Roquetes- Tortosa	13894/14806	39/45	714/742	7/8	23/21	26/24	41/46		
Vielha	2030/2016	6/6	168/143	45/49	27/32	13/15	4/4		
				<i>Cladosporium</i>					
	Spores/m ³			% of days per interval					
Sampling station	Mean AFSIn	Mean daily concentration	Absolute daily maximum	Without	<200	201–500	501–1000	1001–1500	≥ 1501
Barcelona	191758/270949	533/745	6597/6535	0/1	36/22	29/28	21/23	7/13	7/13
Bellaterra	293484/411285	812/1143	16128/9386	0/0	23/13	27/21	24/28	11/13	15/25
Girona	349708/526183	1040/1518	16125/14196	1/2	26/8	23/22	19/20	10/13	21/34
Lleida	593277/1039210	1742/3452	76616/37520	0/1	17/1	17/8	21/15	12/10	33/64
Manresa	452206/622776	1258/1820	21689/27252	0/0	17/6	20/18	23/25	13/14	27/37
Tarragona	201758/275699	589/787	10704/11113	1/1	36/19	29/31	21/25	7/12	8/13
Roquetes- Tortosa	328514/306190	926/946	27205/6583	0/0	25/17	23/24	22/26	12/12	18/20
Vielha	158589/176707	479/511	8557/5454	1/2	53/46	18/21	14/16	7/6	7/9

To validate our models, we have reported the sensitivity and specificity, a quite popular method in biostatistics, especially used in epidemiology (Machin et al. 2007), to measure the predictive power of a model. Sensitivity (percentage of true positives with respect to the total observed positives) and specificity (percentage of true negative with respect to the total of observed negatives) were calculated for each model using the data of the training period. To validate the models, the percentage of coincidences of the outputs of the models and the data obtained during the validation period were calculated.

The validation of the models obtained was based on the percentage of right prediction on the validation period (years 2013–2014).

Results

The summary values for each sampling station of the meteorological parameters considered in this study during the period of training and validation of the models are shown in Table 1. Taking into consideration the data of the training period, Vielha station shows the lowest minimum temperature (4.6 °C) followed by Lleida, Manresa, Bellaterra, Girona,

Tarragona, Barcelona, and Roquetes-Tortosa (12.6 °C). The temperature ranges [Tran] show an inverse relationship with minimum temperature, Barcelona having the lowest average variation (7.9 °C), followed by Tarragona, Roquetes-Tortosa, Bellaterra, Vielha, and Manresa, and ending with Girona and Lleida (12.5 and 13.5 °C, respectively). Finally, the stations reported a wide variation in annual rainfall, the lowest being Lleida (297 mm) and the highest Vielha (856.2 mm). If the rainfall distribution is examined, Vielha is the station where rain occurs more often (34.5% rainy days), and Lleida the one where rain occurs less often (13.8%). Values during the years 2013 and 2014 (validation period) showed some variability with values of the training period. Minimum temperatures were rather stable for Barcelona (−0.1 °C) and Vielha (+0.1 °C); increased in Lleida (0.8 °C), Bellaterra, Manresa, and Roquetes-Tortosa (0.3 °C); and decreased in Tarragona (0.4 °C) and Girona (0.8 °C). The thermal oscillation showed the highest positive variation in Girona (1.5 °C), followed by Tarragona (0.2 °C) and Barcelona (0.1 °C); the highest negative in Vielha (−1.0 °C), followed by Lleida, Bellaterra, and Roquetes-Tortosa (−0.3 °C); and no variation in Manresa. The precipitation decreased in Manresa (56.6 mm) and increased in all the other localities, ranging from Tarragona (15.2 mm) to Vielha (357.6 mm). Finally, the percentage of

rainy days was decreasing in Bellaterra (0.2%) and increasing in the rest of the localities, from Manresa (0.4%) to Tarragona, Barcelona, Girona, Roquetes-Tortosa, Lleida, and Vielha (7.1%).

Table 2 shows a summary of the spore concentrations in the sampling stations studied. If we compare the spore concentrations, *Cladosporium* is 20 times the *Alternaria* values. Lleida reported the highest values, while Vielha showed the lowest values except the *Cladosporium* absolute daily maximum concentration that was registered in Barcelona.

Figure 2 shows the dynamics along the year of airborne *Alternaria* and *Cladosporium* spores in Catalonia during the study period (training and validation periods). In both cases, spores are present almost all the year round, showing the lowest incidence in winter, changing to a peak period in May that lasts to mid-summer, slightly decreasing in August (except in Vielha), and gaining again importance during autumn. Updated information is available at <http://lap.uab.cat/aerobiologia>.

Tables 3 and 4 show the estimates of the coefficients of the explanatory variables for the logistic regression equations, as well as the results of sensitivity and specificity corresponding to the training period and the percentage of right predictions during the validation period. The variation inflation factors (VIF) obtained for all the regressors varied between 1.0 and

1.8, thus dismissing the concerns about multicollinearity. More details about results of the logistic regression are provided as [supplementary material](#).

The equations for *Alternaria* (Table 3) have positive and highly significant coefficients ($p < 0.001$) of minimum temperature and thermal oscillation in all models, except for thermal oscillation in Manresa for thresholds 1 and 10, and Vielha for threshold 30, with lower significance. Precipitation has a negative coefficient in all the equations, significant except in Lleida and Manresa for thresholds 1 and 10. Finally, rainfall in the three previous days has a positive coefficient except in Bellaterra, Girona (for threshold 1), and Lleida (in all cases). However, these coefficients are significant only in two of eight stations in threshold 10 and in five of the eight stations in threshold 30.

The models were evaluated by means of the sensitivity and specificity (Tables 3 and 4). For *Alternaria*, the specificity of threshold ALTE1, that indicates the presence of spores in the air, is very low (Vielha being the only exception) and sensitivity is very high, as expected due to the simplicity of cases to predict. On the contrary, the results for threshold ALTE30, this means the cases where high *Alternaria* concentrations were reached show higher specificity than sensitivity, except in Lleida, where the concentrations are usually very high.

a) *Alternaria*

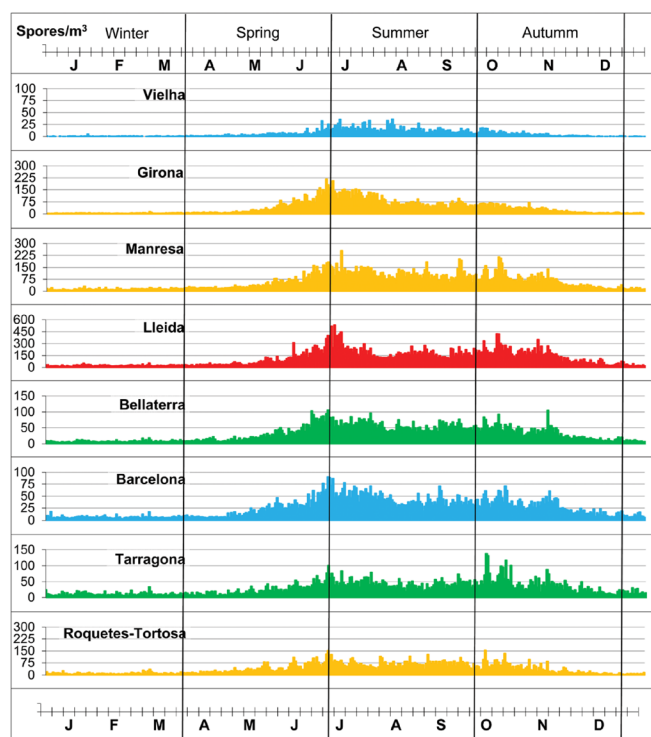
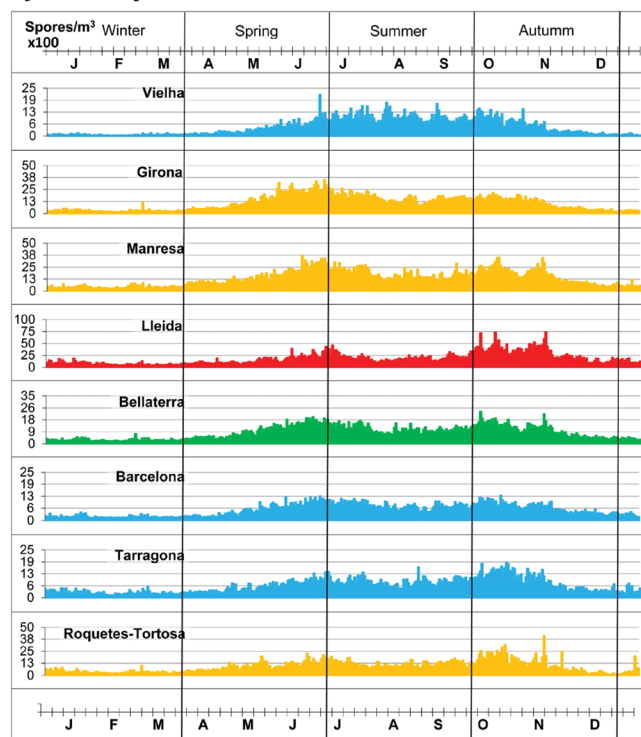


Fig. 2 Yearly dynamics of *Alternaria* (a) and *Cladosporium* (b) spores in the sampling stations. Data shown are the mean daily concentrations along the year during the study period (1995–2014). Colors correspond to y-axis scales and differ in a blue 0–100 spores/m³, green 0–150 spores/

b) *Cladosporium*



m³, orange 0–300 spores/m³, red 0–600 spores/m³; and b blue 0–2500 spores/m³, green 0–3000 spores/m³, orange 0–5000 spores/m³, red 0–10000 spores/m³

Table 3 Results of the logit regression analysis for *Alternaria* spores, with specificity and sensitivity obtained for the training data (1995–2012) and validation results obtained using aerobiological and meteorological data series from years 2013–2014 (Validation period). *Tmin* minimum

temperature, *Tran* thermal oscillation, *Prec* rainfall in the day, *Precpast* rainfall in the three previous days, *Ct* constant. ALTE1 (> 1 spores/m³), ALTE10 (> 10 spores/m³), ALTE30 (≥ 30 spores/m³). *0.01 < *p* < 0.05, **0.001 < *p* < 0.01, ****p* < 0.001

		ALTE1	ALTE10	ALTE30			ALTE1	ALTE10	ALTE30
Barcelona	<i>Tmin</i> β ₁	0.163***	0.183***	0.169***	Manresa	<i>Tmin</i> β ₁	0.064***	0.130***	0.194***
	<i>Tran</i> β ₂	0.137***	0.101***	0.078***		<i>Tran</i> β ₂	0.082**	0.048*	0.108***
	<i>Prec</i> β ₃	−0.570***	−0.685***	−0.669***		<i>Prec</i> β ₃	−0.289	−0.399	−0.623*
	<i>Precpast</i> β ₄	0.144	0.294***	0.421***		<i>Precpast</i> β ₄	0.212	0.339	0.625**
	<i>Ct</i> β ₀	−1.007***	−2.655***	−3.798***		<i>Ct</i> β ₀	0.747	−0.905**	−3.765***
	Specificity	7.5%	68.8%	88.1%		Specificity	0.0%	33.3%	81.4%
	Sensitivity	97.9%	75.6%	36.4%		Sensitivity	100.0%	86.8%	64.6%
	Validation	86.4%	75.1%	72.1%		Validation	97.1%	82.3%	74.1%
Bellaterra	<i>Tmin</i> β ₁	0.176***	0.223***	0.234***	Tarragona	<i>Tmin</i> β ₁	0.150***	0.160***	0.148***
	<i>Tran</i> β ₂	0.125***	0.123***	0.109***		<i>Tran</i> β ₂	0.165***	0.144***	0.143***
	<i>Prec</i> β ₃	−0.559***	−0.888***	−0.870***		<i>Prec</i> β ₃	−0.653***	−0.543***	−0.570***
	<i>Precpast</i> β ₄	−0.015	0.258**	0.681***		<i>Precpast</i> β ₄	0.147	0.257**	0.508***
	<i>Ct</i> β ₀	−0.548**	−2.798***	−4.559***		<i>Ct</i> β ₀	−0.78**	−2.645***	−4.191***
	Specificity	1.8%	61.0%	83.5%		Specificity	1.5%	53.9%	88.4%
	Sensitivity	99.6%	83.8%	66.1%		Sensitivity	99.8%	80.6%	34.7%
	Validation	91.7%	81.3%	75.0%		Validation	89.6%	71.2%	73.9%
Girona	<i>Tmin</i> β ₁	0.189***	0.249***	0.277***	Roquetes-Tortosa	<i>Tmin</i> β ₁	0.240***	0.260***	0.236***
	<i>Tran</i> β ₂	0.152***	0.160***	0.184***		<i>Tran</i> β ₂	0.117***	0.098***	0.130***
	<i>Prec</i> β ₃	−0.568***	−0.695***	−0.477***		<i>Prec</i> β ₃	−1.131***	−0.843***	−0.776***
	<i>Precpast</i> β ₄	−0.116	0.051	0.508***		<i>Precpast</i> β ₄	0.390	0.320*	0.876***
	<i>Ct</i> β ₀	−1.085***	−3.586***	−6.009***		<i>Ct</i> β ₀	−0.816*	−3.124***	−5.154***
	Specificity	7.9%	73.5%	85.0%		Specificity	5.8%	61.4%	81.0%
	Sensitivity	98.6%	82.1%	73.3%		Sensitivity	99.5%	87.5%	72.2%
	Validation	88.6%	81.5%	80.7%		Validation	91.5%	82.2%	83.4%
Lleida	<i>Tmin</i> β ₁	0.098***	0.135***	0.171***	Vielha	<i>Tmin</i> β ₁	0.210***	0.300***	0.265***
	<i>Tran</i> β ₂	0.207***	0.166***	0.108***		<i>Tran</i> β ₂	0.093***	0.113***	0.084**
	<i>Prec</i> β ₃	−0.245	−0.151	−0.454***		<i>Prec</i> β ₃	−0.288*	−0.623***	−1.677***
	<i>Precpast</i> β ₄	−0.227	−0.423***	−0.174		<i>Precpast</i> β ₄	0.041	0.052	0.223
	<i>Ct</i> β ₀	0.718**	−0.710***	−1.749***		<i>Ct</i> β ₀	−2.041***	−4.905***	−6.066***
	Specificity	0.0%	16.8%	53.6%		Specificity	77.0%	93.8%	99.8%
	Sensitivity	100.0%	99.3%	86.9%		Sensitivity	77.4%	41.7%	0.0%
	Validation	99.0%	91.7%	81.4%		Validation	76.7%	85.7%	96.4%

Table 4 shows the results of the models for *Cladosporium*. In all models (thresholds 200, 500, 1000, and 1500 spores/m³), the minimum temperature, thermal oscillation, and rainfall in the three previous days were positively correlated. The precipitation had a negative relationship, except in Roquetes-Tortosa for thresholds 200, 500, and 1500. Statistical significance has been obtained for minimum temperature, thermal oscillation, and rainfall in the three previous days, although in Manresa, the relationship of thermal oscillation is low. In Lleida and Vielha, the rainfall in the three previous day's relationship is weaker. The precipitation is nonsignificant, except for Vielha and Barcelona stations.

In general, the results of specificity and sensitivity for *Cladosporium* models (Table 4) are quite satisfactory. Since the percentages of days in which more than 200 *Cladosporium* spores per cubic meter are very frequent in most of the sites (Table 2), the specificity is lower than sensitivity in the CLAD200 column (i.e., Lleida, 1.6% versus 99.9%; and Bellaterra, 20.9% versus 94.8%). CLAD200 shows the best results in Vielha, with low spore concentrations, with similar values for specificity (79.0%) and sensitivity (81.0%).

In general, as shown in Tables 3 and 4, the models work better for the prediction of the lowest thresholds than for the highest.

Table 4 Results of the logit regression analysis for *Cladosporium* spores, with specificity and sensitivity obtained for the training data (1995–2012) and validation results obtained using aerobiological and meteorological data series from years 2013–2014 (validation period). *Tmin* minimum temperature, *Tran* thermal oscillation, *Prec* rainfall in the day, *Precpast* rainfall in the three previous days, *Ct* constant, CLAD200 (> 200 spores/m³), CLAD500 (> 500 spores/m³), CLAD1000 (> 1000 spores/m³), CLAD1500 (> 1500 spores/m³). *0.01 < *p* < 0.05, **0.001 < *p* < 0.01, ****p* < 0.001

	CLAD200	CLAD500	CLAD1000	CLAD1500		CLAD200	CLAD500	CLAD1000	CLAD1500
Barcelona	Tmin β ₁	0.179***	0.141***	0.111***	0.100***	Manresa	Tmin β ₁	0.095***	0.129***
	Tran β ₂	0.092***	0.058***	0.055	0.068		Tran β ₂	0.012	0.058**
	Prec β ₃	-0.598***	-0.644***	-0.675***	-0.519**		Prec β ₃	-0.542	-0.300
	Precpast β ₄	0.547***	0.597***	0.601***	0.646***		Precpast β ₄	1.002***	0.831***
	Ct β ₀	-2.163***	-2.958***	-3.806***	-4.613***		Ct β ₀	-0.397	-2.228***
	Specificity	52.6%	83.5%	100.0%	100.0%		Specificity	32.2%	71.4%
	Sensitivity	84.0%	44.5%	0.0%	0.0%		Sensitivity	87.3%	65.2%
	Validation	76.3%	67.8%	74.4%	87.2%		Validation	86.5%	67.8%
	Tmin β ₁	0.187***	0.159***	0.133***	0.126***	Tarragona	Tmin β ₁	0.154***	0.131***
	Tran β ₂	0.150***	0.108***	0.097***	0.082***		Tran β ₂	0.139***	0.123***
Bellaterra	Prec β ₃	-0.165	-0.333	-0.233*	-0.166		Prec β ₃	-0.120	-0.039
	Precpast β ₄	0.531***	0.749***	0.833***	0.974***		Precpast β ₄	0.396***	0.526***
	Ct β ₀	-2.154***	-3.038***	-3.902***	-4.518***		Ct β ₀	-2.384***	-3.488***
	Specificity	20.9%	70.5%	92.4%	99.8%		Specificity	40.4%	81.0%
	Sensitivity	94.8%	73.5%	15.1%	0.7%		Sensitivity	86.9%	43.9%
	Validation	84.0%	73.2%	65.7%	75.1%		Validation	78.5%	66.5%
	Tmin β ₁	0.187***	0.174***	0.175***	0.164***	Roquetes-Tortosa	Tmin β ₁	0.219***	0.181***
	Tran β ₂	0.138***	0.151***	0.154***	0.145***		Tran β ₂	0.137***	0.083***
	Prec β ₃	-0.213	-0.039	-0.076	-0.088		Prec β ₃	0.092	0.037
	Precpast β ₄	0.411***	0.657***	0.859***	1.004***		Precpast β ₄	1.024***	0.895***
Girona	Ct β ₀	-1.876***	-3.563***	-4.836***	-5.349***		Ct β ₀	-2.944***	-3.366***
	Specificity	21.6%	70.7%	82.0%	94.0%		Specificity	39.7%	71.0%
	Sensitivity	95.2%	77.3%	51.2%	17.1%		Sensitivity	92.8%	76.4%
	Validation	87.6%	78.4%	71.3%	69.3%		Validation	83.7%	79.9%
	Tmin β ₁	0.112***	0.112***	0.111***	0.102***	Vielha	Tmin β ₁	0.280***	0.256***
	Tran β ₂	0.099***	0.042***	0.002	-0.011		Tran β ₂	0.089***	0.100***
	Prec β ₃	-0.017	-0.190	-0.143	-0.212		Prec β ₃	-0.536***	-0.613***
	Precpast β ₄	-0.116	0.209*	0.412***	0.583***		Precpast β ₄	0.272*	0.382
	Ct β ₀	-0.122	-0.491***	-1.129***	-1.504***		Ct β ₀	-2.318***	-3.712***
	Specificity	1.6%	23.8%	67.1%	85.4%		Specificity	79.0%	86.9%
Lleida	Sensitivity	99.9%	91.9%	65.3%	36.0%		Sensitivity	81.0%	57.5%
	Validation	98.2%	88.0%	66.1%	48.3%		Validation	83.2%	81.6%
	Tmin β ₁	0.168***	0.154***	0.168***	0.154***		Tmin β ₁	0.168***	0.154***
	Tran β ₂	0.054*	0.020	0.054*	0.020		Tran β ₂	0.054*	0.020
	Prec β ₃	-0.670*	-0.496	-0.670*	-0.496		Prec β ₃	-0.670*	-0.496
	Precpast β ₄	1.247***	1.148***	1.247***	1.148***		Precpast β ₄	1.247***	1.148***
	Ct β ₀	-3.825***	-3.925***	-3.825***	-3.925***		Ct β ₀	-3.825***	-3.925***
	Specificity	92.8%	99.4%	92.8%	99.4%		Specificity	92.8%	99.4%
	Sensitivity	23.0%	1.4%	23.0%	1.4%		Sensitivity	23.0%	1.4%
	Validation	61.6%	65.2%	61.6%	65.2%		Validation	61.6%	65.2%

For the validation of the models obtained, we have used the data of 2013–2014. The percentages of right prediction for each model are reported in Tables 3 and 4. In the case of *Alternaria*, ALTE1 shows values between 77 and 99%, ALTE10 between 75 and 92%, and ALTE30 between 72 and 96%. In the case of *Cladosporium* spores (Table 4), threshold 200 shows percentages of right prediction of 76–98%, threshold 500 of 67–88%, threshold 1000 of 62–86%, and threshold 1500 of 48–91%.

To illustrate the application of the models obtained, Table 5 shows examples for each model. We consider positive predictions those for which the predicted probability exceeds 0.5, and negative those where it does not. The last column in Table 5 shows the actual concentrations of spores registered for validation.

Discussion

The use of statistical models for the prevention of allergic symptoms and phytopathologies of crops has increased in recent years. Many widely used methods involve complicated statistical techniques, or the predictive models obtained require many variables. De Linares et al. (2010) successfully employed a logistic regression approach to estimate and to verify the influence of the meteorological variables on the Annual *Alternaria* Spore Integral; the aim of our study was to adapt this

methodology for the prediction of the daily levels of *Alternaria* and *Cladosporium* spore concentrations.

This paper presents models based on maximum and minimum temperatures and precipitation. Since forecasts on these meteorological variables are currently available in many websites, these models propose an easy system for providing daily forecasts of spore presence and threshold exceedance in the air.

On the one side, the simplification of the variables related to the precipitation as dummy variables (0 or 1 according to whether it occurs or not) makes the models even simpler, but also fits with the fact that the forecasted meteorological information usually gives a probability for the precipitation, not an amount. Another reason for using dummy variables in regression equations is the mechanical procedure of “dropping out” one of the variables in the system (Suits 1984).

On the other hand, our results show the strong relationship between the daily meteorological parameters and airborne spore concentrations, although the influence is not the same for all parameters. As other authors have also shown (Rodríguez-Rajo et al. 2005; Stępańska and Wołek, 2005; Grinn-Gofroń and Rapiejko 2009; Oliveira et al. 2009a, b; Reyes et al. 2009; Recio et al. 2012; Grinn-Gofroń and Strzelczak 2013; Grinn-Grofoń et al. 2019), the *p* values show higher significance for temperature than for rainfall. Minimum temperature and thermal oscillation variables have a positive relationship in all models. This agrees with Lewis et al.

Table 5 Example of the application of the logistic models using data from year 2013. β_1 *Tmin* minimum temperature, β_2 *Tran* thermal oscillation, β_3 *Prec* rainfall in the day, β_4 *Precpast* rainfall in the three previous days, β_0 constant. ALTE1 (> 1 spores/m³), ALTE10 (> 10 spores/m³), ALTE30 ($\geq$ 30 spores/m³), CLAD200 (> 200 spores/m³),

CLAD500 (> 500 spores/m³), CLAD1000 (> 1000 spores/m³), CLAD1500 ($\geq$ 1500 spores/m³). So if this value is lower than 0.5, this variable is 0, and if higher than 0.5, the variable is 1. Logit results: when the value is higher than 0.5, it indicates that the concentration reaches this range

<i>Alternaria</i> logistic model = $\beta_0 + \beta_1$ Tmin + β_2 Tran + β_3 Prec + β_4 Precpast										
Meteorological parameters						Logit model results			Observed value (for validation)	
Site	Date	Tmin	Tran	Prec	Precpast	ALTE 1	ALTE 10	ALTE 30	<i>Alternaria</i> (spores/m ³)	
Barcelona	28 Feb	4.0	2.9	10.4	10.8	0.4	0.1	0.0	0	
Bellaterra	22 Jan	3.2	8.4	4.6	4.9	0.6	0.2	0.0	3	
Girona	12 Sep	12.0	12.3	1.1	3.7	0.9	0.7	0.4	28	
Tarragona	25 Aug	17.1	12.4	0.0	0.0	1.0	0.9	0.6	174	
<i>Cladosporium</i> logistic model = $\beta_0 + \beta_1$ Tmin + β_2 Tran + β_3 Prec + β_4 Precpast										
Meteorological parameters						Logit model results				Observed value for validation
Site	Date	Tmin	Tran	Prec	Precpast	CLAD 200	CLAD 500	CLAD 1000	CLAD 1500	<i>Cladosporium</i> (spores/m ³)
Vielha	19 Jan	6.0	6.5	9.5	9.9	0.4	0.2	0.1	0.0	132
Tarragona	29 May	9.9	10.8	0.0	0.0	0.7	0.3	0.1	0.0	344
Manresa	22 Mar	3.0	17.0	0.0	1.5	0.8	0.5	0.3	0.1	618
Roquetes-Tortosa	01 Oct	20.3	14.2	0.0	0.0	1.0	0.9	0.7	0.4	1226
Lleida	20 Jun	13.2	11.9	0.0	22.8	1.0	0.8	0.6	0.5	16,979

(2000), Grinn-Gofroń and Strzelczak (2013), Grinn-Gofroń and Bosiacka (2015), Damialis et al. (2015), and Sousa et al. (2016) which reported that an increasing temperature has a positive relationship with the *Alternaria* concentrations. Actually, the meta-analysis carried out by Kasprzyk (2008) based on aerobiological studies from different parts of the world showed that in temperate climates, the maximum concentration of most spores occurs in summer or early autumn. This agrees with annual dynamics of airborne spores shown in Fig. 2, where the concentrations tend to increase from May and decrease close to October.

The daily rainfall parameter shows a significant negative relationship, which is in agreement with the observation by Fitt et al. (1989) and Burch and Levetin (2002) on the action of heavy or prolonged rainfall cleaning the air temporarily. Peternel et al. (2004) reported higher concentrations of *Alternaria* spores in the years with less precipitations, and Corden and Millington (2001) reported higher values on days without rainfall. Likewise, in *Alternaria*, the presence of rainfall in previous days (shown by Precpast) provokes an increase in their concentrations, possibly due to that the light rain or dew can stimulate the sporulation (van der Waals et al. 2003; Knutsen et al. 2012).

Cladosporium also shows a high and positive correlation with the temperature that agrees with other studies (Kasprzyk et al. 2016; Sindt et al. 2016; Almeida et al. 2018). *Cladosporium* is recognized as a dry spore, although Knutsen et al. (2012) asseverated that their sporulation can occur in both wet and dry conditions. In any case and according to the literature, the levels of spores tend to be higher in warmer weather (Lewis et al. 2000; Troutt and Levetin 2001; Burch and Levetin 2002). The positive relationship obtained with the Precpast is in agreement also with Kurkela (1997) and Knutsen et al. (2012) which showed that during the rainfall, the relative humidity increases and the sporulation is induced.

The study of specificity and sensitivity of our results shows that the behavior of the models is influenced by the spore concentrations and by the thresholds proposed. If spore levels usually attain the thresholds, the model always predicts that there will be spores. On the other side, if spore levels are very low (i.e., Vielha with more than 40% of the days without *Alternaria* spores, and only 4% of the days with more than 31 spores/m³; Table 2), the model never predicts that the highest thresholds will be attained (the specificity in the threshold 30 is 99.8% while sensibility is 0.0%). On the contrary, when in a model, the percentage of spores is high (in Lleida, 0.0% of the days without *Cladosporium* spores; Table 2), the specificity in the threshold 200 (1.6%) is smaller than the sensitivity (99.9%). These results show the reliability of the models to estimate the thresholds of spore concentrations. Despite that logistic regression is a flexible and easy to interpret model, some authors have established that the

selection of the critical point value in the prediction could be the most complex to fix it (Hosmer and Lemeshow 2000; Rojas et al. 2001). Some strategies to correct this impasse consisted on the selection of a subsample with a 50:50 ratio (Brito et al. 1999) or the use of weighting factors (Teixeira et al. 2001). However, these strategies tend to generate a great loss of information or simply alter the original database, so determining the optimal cutoff point by developing the model with different critical values turns out to be one of the best accepted strategies in the development of this type of models (Rojas et al. 2001; Barbosa et al. 2003).

Taking into account that the values between 60 and 70% are considered a poor fit, those between 70 and 80% are acceptable, those ranging from 80 to 90% suggest excellent discrimination, and values above 90% are outstanding (Hosmer and Lemeshow 2000; Crawford et al. 2015), the validation results (Tables 3 and 4) show that the models worked better for *Alternaria* (from 71.2 to 99.0%) than for *Cladosporium* (from 48.3 to 98.2%). *Alternaria* logistic model validations are over 90% in 25% of the cases, over 75% in 83.3% of the cases, and over 70% in 100%; *Cladosporium* equivalent validation results are 6.3%, 59.4%, and 71.9%. Considering all the models together and the validations in over 75% of the cases, CLAD200 and ALTE10 are the ones performing better, followed, in decreasing order, by ALTE1, CLAD1500, ALTE30, CLAD500, and CLAD1000.

In the case of *Alternaria* (Table 3), taking into account the values of the validation, Lleida, followed by Roquetes-Tortosa and Girona, is the locality best modeled for *Alternaria*, despite the fact that they are localities where during the validation period, there were important rainy conditions (annual values and increment of rainy days), only exceeded by Vielha. Considering the results per model and sampling station, ALTE1 gives better results than ALTE10 and this one is better than ALTE30, the exceptions being Vielha (which results are ordered just the contrary), Tarragona, and Roquetes-Tortosa (where ALTE30 is slightly better estimated than ALTE10). The case of Vielha can be due to the few concentrations over 30 spores/m³ and the abundance of days under 1 spores/m³, which make it easy to predict the results.

In the case of *Cladosporium* (Table 4), considering the values of the validation, Lleida is the station presenting at the same time the best results (98.2% for CLAD200) and the worst (48.3% for CLAD1500) and the second worst result is 61.6% for CLAD1000 in Manresa. As shown in Table 1, the meteorological conditions during the validation period in Lleida were warmer and less variable than during the training period and there were more rain and more rainy days. As a consequence, the percentages of days with concentrations higher than 1500 spores/m³ have doubled and the days with the lower concentration levels have suffered a drastic reduction (Table 2). The models giving better predictions are CLAD200 (Lleida, Girona, Manresa, Bellaterra, and

Roquetes-Tortosa in the first position and Tarragona and Barcelona in the second position) and CLAD1500 (Vielha, Tarragona, and Barcelona in the first position and Roquetes-Tortosa and Bellaterra in the second one).

The logistic models proposed in this study can be improved, as any model do, by incorporating more training data. However, with the present data, the proposed models can be incorporated to elaborate the prediction system used by Point of Information on Aerobiology of Catalonia, because it allows generating a quick and fairly good prevision of *Alternaria* and *Cladosporium* spore thresholds.

Conclusions

This paper presents a simple predictive methodology, based on logistic regression equations, for the occurrence of three thresholds of *Alternaria* (1, 10, and 30 spores/m³) and four thresholds of *Cladosporium* (200, 500, 1000, and 1500 spores/m³) in the air. The model uses four explanatory variables derived from temperature (maximum and minimum) and precipitation data. Since forecasts of these meteorological variables are currently available on many websites, this model allows us not only just to describe the statistical dependence between meteorology and spore presence in the air, but also to obtain from extremely good to good daily forecasts. The simplification of the variables related to the precipitation, which enter the model as dummies, makes this even simpler.

The prediction models for *Alternaria* and *Cladosporium* spore levels presented in this study can help to prevent the exposure of affected beings (humans, animals, and plants) and environments to these airborne spores.

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Table 1S. Percentage confusion matrix for *Alternaria* logistic models to 2013 and 2014 years (testing years)

			Modelling								
			Model ALTE 1			Model ALTE 10			Model ALTE 30		
			False	True	Total	False	True	Total	False	True	Total
Measured	BCN	False	0,6%	11,8%	12,4%	28,6%	13,9%	42,5%	61,8%	8,8%	70,6%
		True	1,2%	86,4%	87,6%	11,0%	46,5%	57,5%	19,1%	10,3%	29,4%
		Total	1,8%	98,2%	n=727	39,6%	60,4%	n=727	80,9%	19,1%	n=727
	BTU	False	0,1%	8,2%	8,3%	24,7%	11,7%	36,4%	54,0%	14,2%	68,2%
		True	0,1%	91,5%	91,7%	7,1%	56,5%	63,6%	10,8%	21,0%	31,8%
		Total	0,3%	99,7%	n=720	31,8%	68,2%	n=720	64,9%	35,1%	n=720
	GIC	False	0,7%	10,1%	10,8%	31,7%	8,1%	39,8%	53,7%	7,5%	61,2%
		True	1,3%	87,9%	89,2%	10,4%	49,8%	60,2%	11,8%	27,0%	38,8%
		Total	2,0%	98,0%	n=693	42,1%	57,9%	n=693	65,5%	34,5%	n=693
	LLE	False	0,0%	1,0%	1,0%	1,5%	7,5%	9,0%	13,8%	10,0%	23,8%
		True	0,0%	99,0%	99,0%	0,8%	90,2%	91,0%	8,6%	67,6%	76,2%
		Total	0,0%	100,0%	n=602	2,3%	97,7%	n=602	22,4%	77,6%	n=602
	MAN	False	0,0%	2,9%	2,9%	10,1%	10,2%	20,4%	37,9%	5,4%	43,3%
		True	0,0%	97,1%	97,1%	7,5%	72,2%	79,6%	20,5%	36,2%	56,7%
		Total	0,0%	100,0%	n=683	17,6%	82,4%	n=683	58,4%	41,6%	n=683
	TOR	False	0,2%	8,2%	8,4%	18,7%	10,7%	29,4%	47,7%	5,9%	53,6%
		True	0,3%	91,3%	91,6%	7,1%	63,5%	70,6%	10,7%	35,8%	46,4%
		Total	0,5%	99,5%	n=646	25,9%	74,1%	n=646	58,4%	41,6%	n=646
	TAU	False	0,0%	10,4%	10,4%	19,4%	19,2%	38,6%	59,8%	10,0%	69,8%
		True	0,0%	89,6%	89,6%	9,5%	51,9%	61,4%	16,1%	14,1%	30,2%
		Total	0,0%	100,0%	n=702	28,9%	71,1%	n=702	75,9%	24,1%	n=702
	VIE	False	37,4%	11,9%	49,3%	77,5%	4,2%	81,7%	96,4%	0,0%	96,4%
		True	11,4%	39,3%	50,7%	10,1%	8,1%	18,3%	3,6%	0,0%	3,6%
		Total	48,8%	51,2%	n=690	87,7%	12,3%	n=690	100,0%	0,0%	n=690

BCN: Barcelona, BTU: Bellaterra, GIC: Girona, LLE: Lleida, MAN: Manresa, TAU: Tarragona, TOR: Roquetes-Tortosa, VIE: Vielha.

Table 2S. Percentage Confusion matrix for *Cladosporium* logistic models to 2013 and 2014 years (testing years)

			Modelling											
			Model CLAD 200			Model CLAD 500			Model CLAD 1000			Model CLAD 1500		
			False	True	Total	False	True	Total	False	True	Total	False	True	Total
			False	True	Total	False	True	Total	False	True	Total	False	True	Total
Measured	BCN	False	13,9%	9,4%	23,2%	43,3%	8,0%	51,3%	74,4%	0,1%	74,6%	87,2%	0,0%	87,2%
		True	14,3%	62,4%	76,8%	24,2%	24,5%	48,7%	25,4%	0,0%	25,4%	12,8%	0,0%	12,8%
		Total	28,2%	71,8%	n=727	67,5%	32,5%	n=727	99,9%	0,1%	n=727	100,0%	0,0%	n=727
	BTU	False	3,1%	10,1%	13,2%	28,3%	6,3%	34,6%	58,8%	3,3%	62,1%	75,0%	0,3%	75,3%
		True	5,8%	81,0%	86,8%	20,6%	44,9%	65,4%	31,0%	6,9%	37,9%	24,6%	0,1%	24,7%
		Total	8,9%	91,1%	n=720	48,9%	51,1%	n=720	89,7%	10,3%	n=720	99,6%	0,4%	n=720
	GIC	False	2,5%	7,4%	9,8%	25,4%	6,8%	32,2%	47,2%	5,5%	52,7%	60,8%	4,9%	65,7%
		True	5,1%	85,1%	90,2%	14,9%	53,0%	67,8%	23,2%	24,1%	47,3%	25,8%	8,5%	34,3%
		Total	7,5%	92,5%	n=693	40,3%	59,7%	n=693	70,4%	29,6%	n=693	86,6%	13,4%	n=693
	LLE	False	0,3%	1,8%	2,2%	1,5%	9,1%	10,6%	20,4%	5,6%	26,1%	33,9%	1,8%	35,7%
		True	0,0%	97,8%	97,8%	2,8%	86,5%	89,4%	28,2%	45,7%	73,9%	49,8%	14,5%	64,3%
		Total	0,3%	99,7%	n=602	4,3%	95,7%	n=602	48,7%	51,3%	n=602	83,7%	16,3%	n=602
	MAN	False	2,8%	2,9%	5,7%	20,6%	3,2%	23,9%	45,8%	2,6%	48,5%	5%	1,5%	63,0%
		True	7,6%	86,7%	94,3%	29,0%	47,1%	76,1%	35,7%	15,8%	51,5%	33,4%	3,7%	37,0%
		Total	10,4%	89,6%	n=683	49,6%	50,4%	n=683	81,6%	18,4%	n=683	94,9%	5,1%	n=683
	TOR	False	5,7%	11,8%	17,5%	28,8%	12,7%	41,5%	58,8%	8,8%	67,6%	78,2%	1,4%	79,6%
		True	4,5%	78,0%	82,5%	7,4%	51,1%	58,5%	18,0%	14,4%	32,4%	19,0%	1,4%	20,4%
		Total	10,2%	89,8%	n=646	36,2%	63,8%	n=646	76,8%	23,2%	n=646	97,2%	2,8%	n=646
	TAU	False	8,7%	11,7%	20,4%	43,9%	7,3%	51,1%	75,4%	0,3%	75,6%	87,5%	0,0%	87,5%
		True	9,8%	69,8%	79,6%	26,2%	22,6%	48,9%	23,9%	0,4%	24,4%	12,5%	0,0%	12,5%
		Total	18,5%	81,5%	n=702	70,1%	29,9%	n=702	99,3%	0,7%	n=702	100,0%	0,0%	n=702
	VIE	False	39,9%	8,4%	48,3%	63,2%	6,4%	69,6%	83,8%	1,6%	85,4%	91,2%	0,0%	91,2%
		True	8,4%	43,3%	51,7%	12,0%	18,4%	30,4%	12,6%	2,0%	14,6%	8,8%	0,0%	8,8%
		Total	48,3%	51,7%	n=690	75,2%	24,8%	n=690	96,4%	3,6%	n=690	100,0%	0,0%	90

BCN: Barcelona, BTU: Bellaterra, GIC: Girona, LLE: Lleida, MAN: Manresa, TAU: Tarragona, TOR: Roquetes-Tortosa, VIE: Vielha.

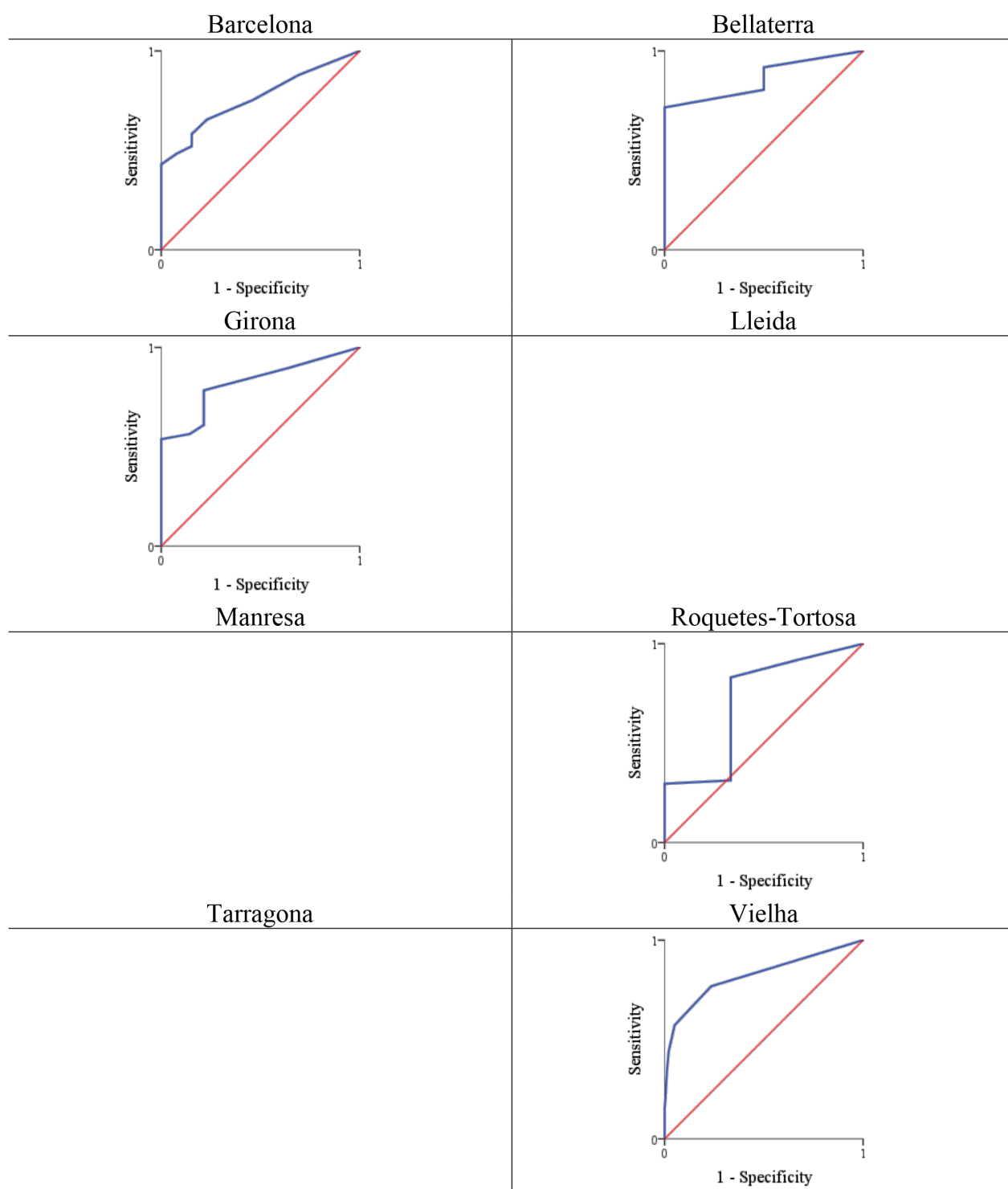


Figure 1S. ROC curves of [ALTE 1] logistic model to 2013 and 2014 years (testing years). NOTE: If the station does not show a ROC curve is due to sensibility or specificity is equal to zero

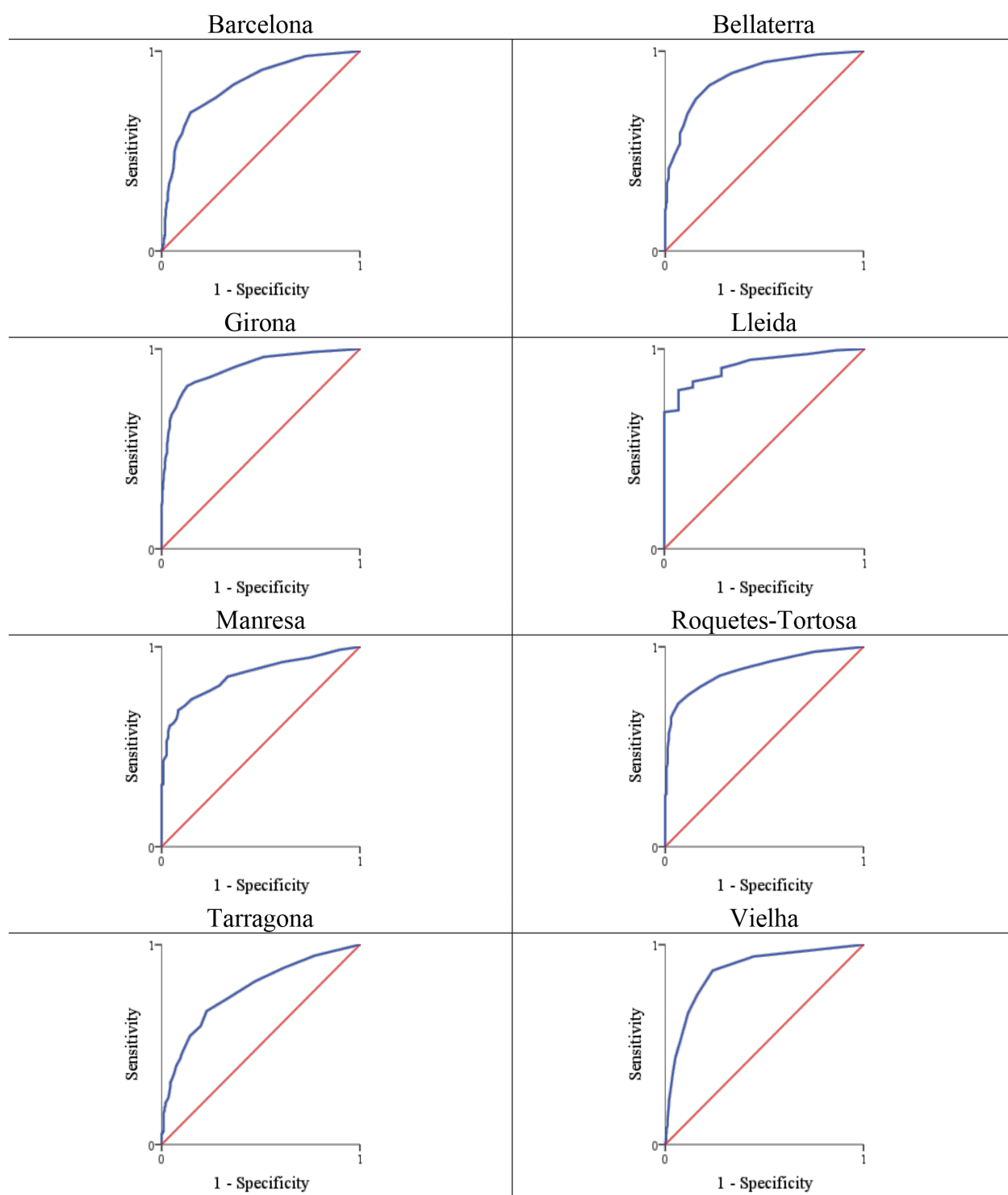


Figure 2S. ROC curves of [ALTE 10] logistic model to 2013 and 2014 years (testing years). NOTE: If the station does not show a ROC curve is due to sensibility or specificity is equal to zero

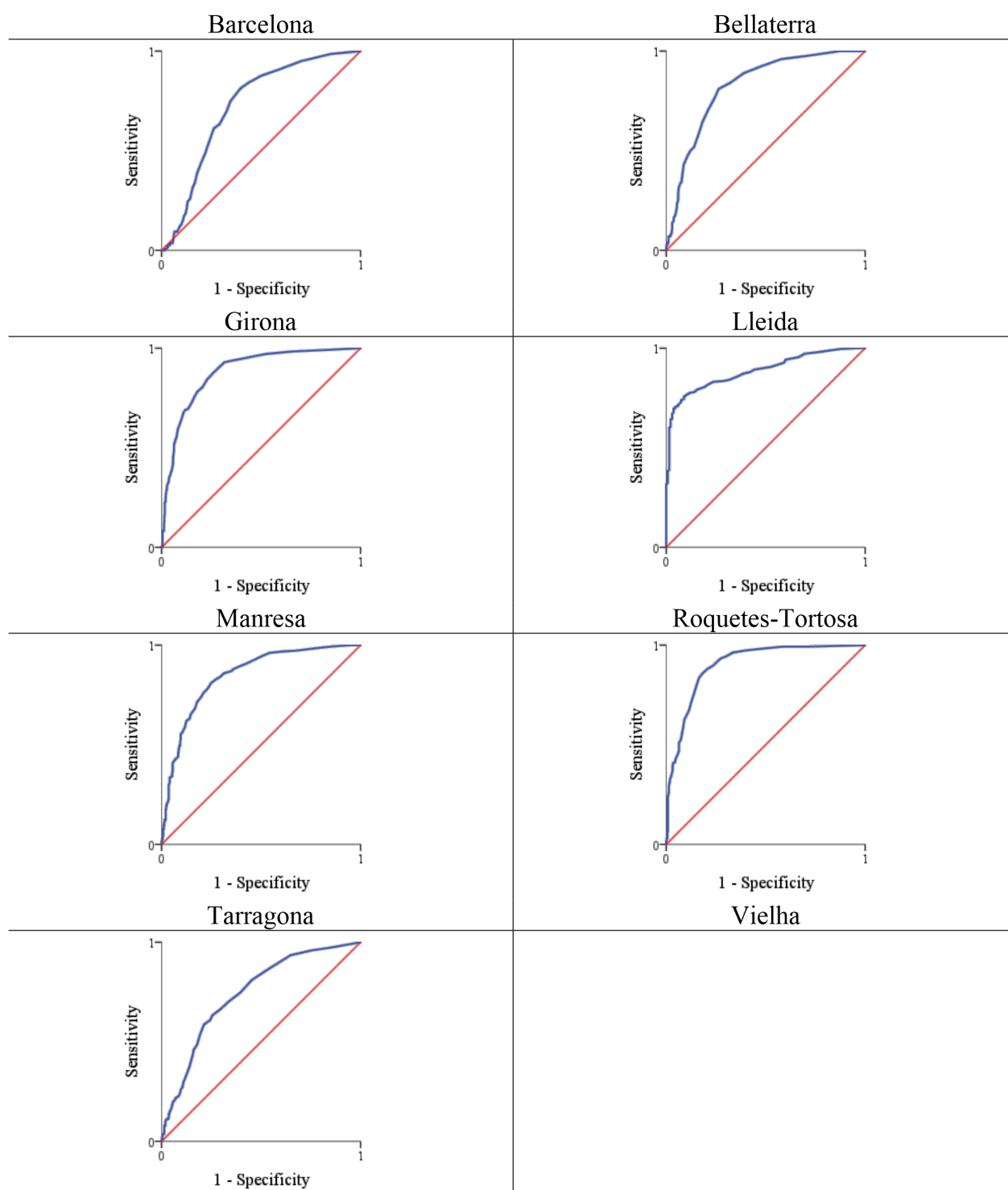


Figure 3S. ROC curves of [ALTE 30] logistic model to 2013 and 2014 years (testing years). NOTE: If the station does not show a ROC curve is due to sensibility or specificity is equal to zero

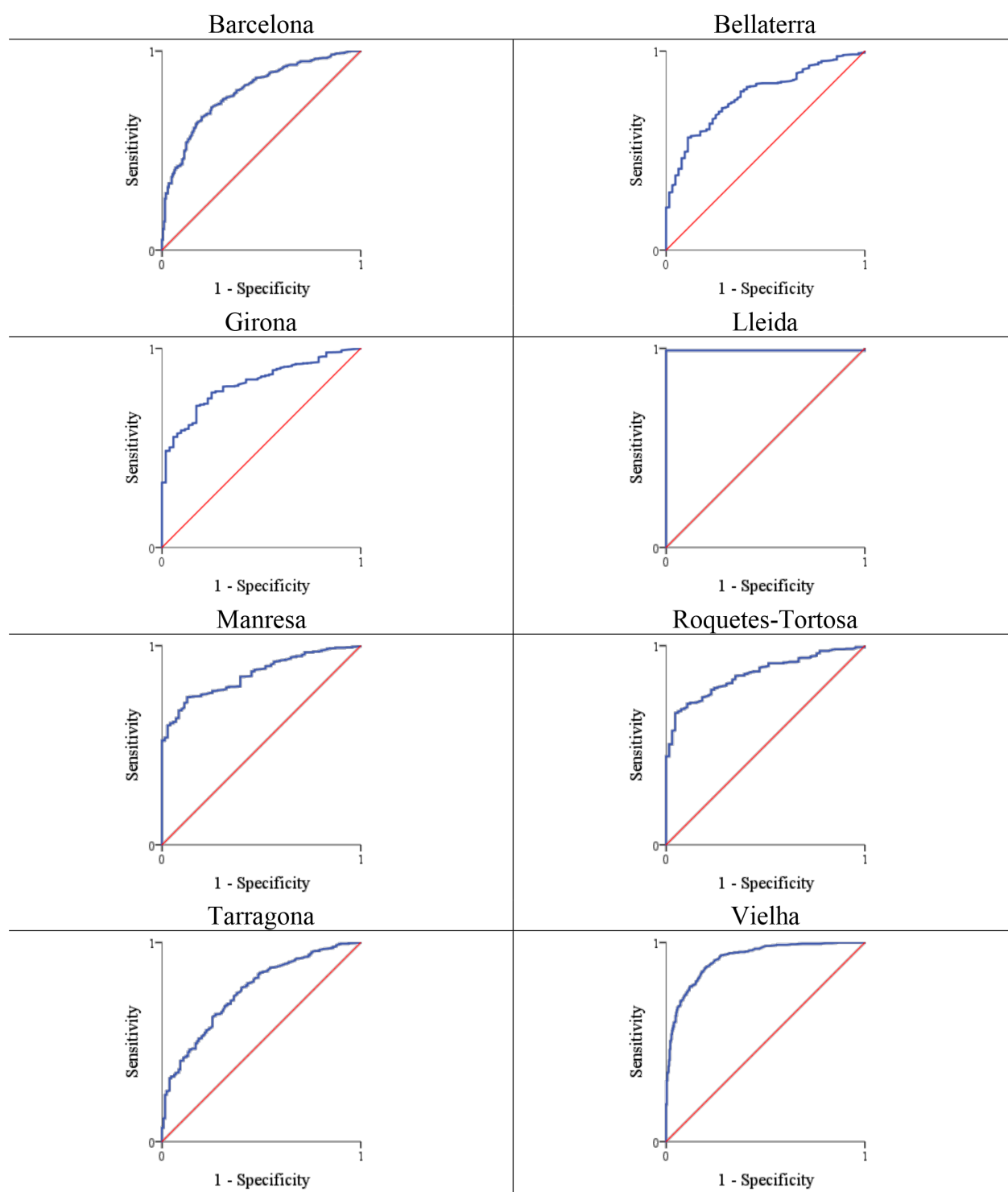


Figure 4S. ROC curves of [CLAD 200] logistic model to 2013 and 2014 years (testing years). NOTE: If the station does not show a ROC curve is due to sensibility or specificity is equal to zero

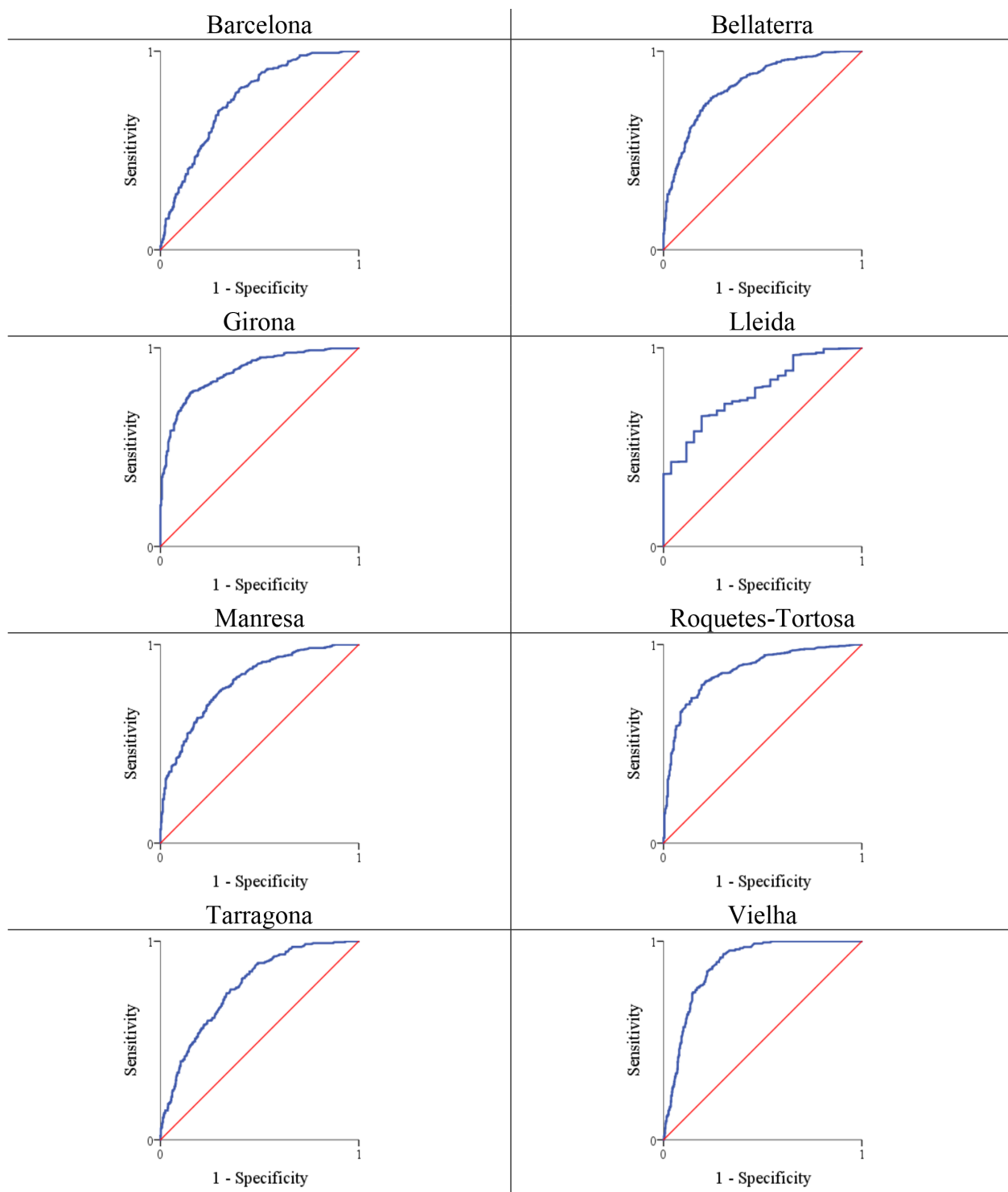


Figure 5S. ROC curves of [CLAD 500] logistic model to 2013 and 2014 years (testing years). NOTE: If the station does not show a ROC curve is due to sensibility or specificity is equal to zero

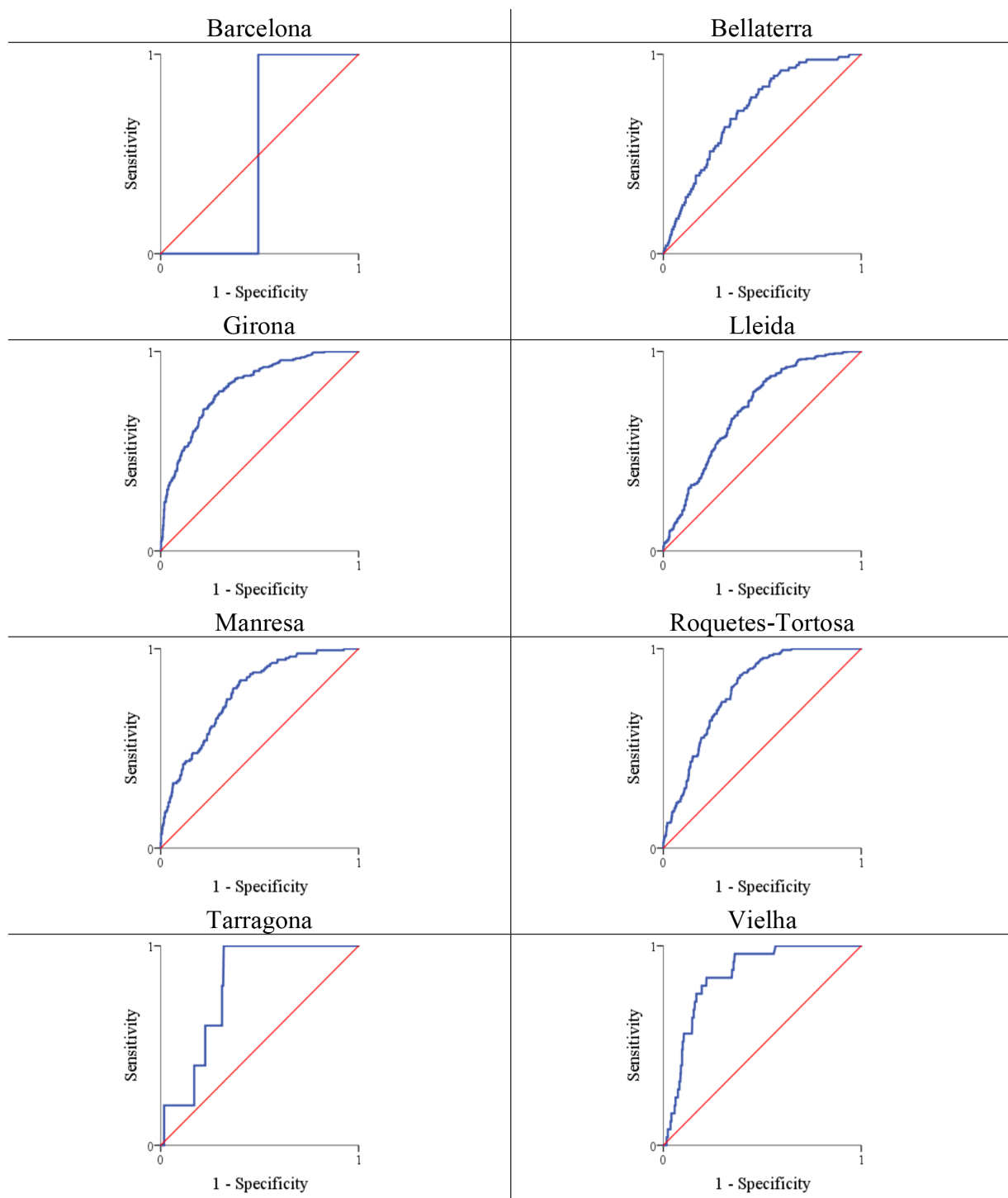


Figure 6S. ROC curves of [CLAD 1000] logistic model to 2013 and 2014 years (testing years). NOTE: If the station does not show a ROC curve is due to sensibility or specificity is equal to zero

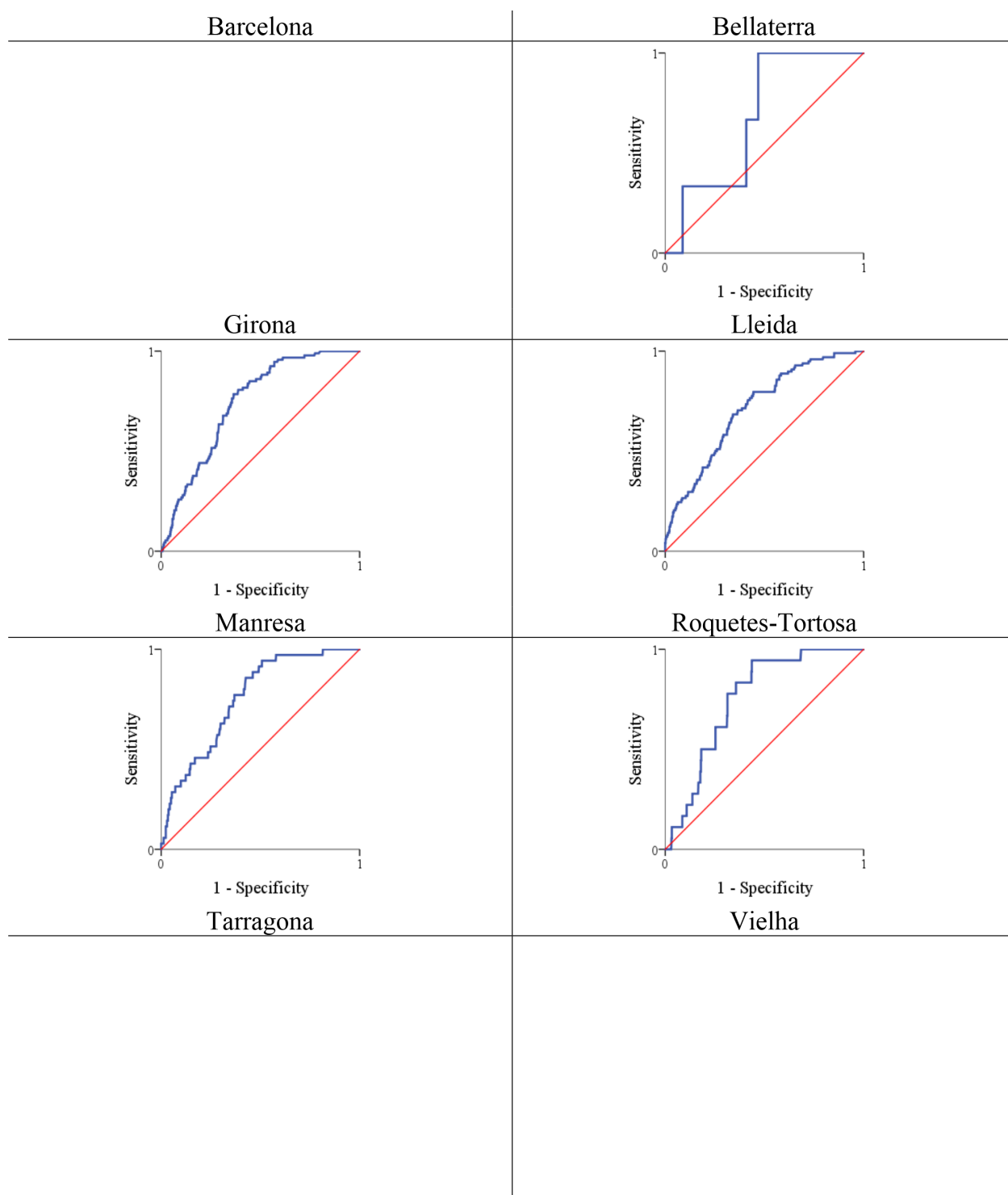


Figure 7S. ROC curves of [CLAD 1500] logistic model to 2013 and 2014 years (testing years). NOTE: If the station does not show a ROC curve is due to sensibility or specificity is equal to zero