Design of a downscaling method to estimate continuous data from discrete pollen monitoring in Tunisia.

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Data provided by continuous Hirst air sampling are used to reconstruct discrete Cour air sampler data through an interpolation method for the potential use of Cour databases for scientific purposes.

Abstract

The study of microorganisms and biological particulate matter transported passively though the air is very important for an understanding of the real quality of the air. Such monitoring is essential in several specific areas, such as public health, allergy studies, agronomy, indoor and outdoor conservation, and climate-change impact studies. Choosing the suitable monitoring method is an important step in aerobiological studies, so as to obtain reliable airborne data. In this study, we compare olive pollen data from two of the main air traps used on aerobiology, the Hirst and Cour air samplers, at three Tunisian sampling points, for 2009 to 2011. Moreover, a downscaling method to perform daily Cour air sampler data estimates is designed. While Hirst air samplers can offer daily, and even bi-hourly, data, Cour air samplers provide data through longer discrete sampling periods, which limits their usefulness for daily monitoring. Higher quantities of olive pollen capture were generally detected for the Hirst air sampler, and a downscaling method that is developed in this study is used to model these differences. The effectiveness of this downscaling method is demonstrated, which allows the potential use of Cour air sampler data series. These results improve the information that new Cour data and, importantly, historical Cour databases, can provide for the understanding of phenological dates, airborne pollination curves, and allergenicity levels of the air.

Keywords: Atmospheric monitoring; Pollen; Aerobiology; Sampling method; Downscaling method; Air spore trap.

Environmental impact statement

The study of micro organisms and biological particulate matter transported passively though the air is very important to understand the real quality of the atmosphere. The monitoring of these particles is essential in several areas as public health, allergy studies, agronomy, indoor and outdoor conservation or in climate change impact studies, among other fields. The presented method for the daily data downscaling allows the exploitation of the potential of particular no-volumetric aerobiological sampler utilized in several investigation areas of the world. The present study shows the design of a new method with which to estimate the daily data using a nonlinear approach which has been extensively studied and analyzed across many scientific and technological fields.

1. Introduction

Aerobiology is the study of the passive transport of microorganisms and biological particulate matter through the air [1]. This science can provide important information that can be applied in various disciplines and for various studies, such as for allergies in preventive medicine [2,3], for development of crop forecasting and management, and pest control, in agronomy [4,5], for climate-change studies [6-9], and for our cultural heritage, in terms of both indoor and outdoor conservation [10].

Aerobiology is a multi-disciplinary field and thus requires the appropriate methodological approaches. In this sense, several studies have worked on the standardization of a range of methodological issues. These have including the selection of the air-spore trap method [11] and the effective comparison of data that can be obtained at different altitudes and in different locations. [12-14]

There is a wide range of instruments available that can directly monitor the presence of viable and non-viable microorganisms or biological particles, and complex processes are often required to identify the material collected. Air sampling techniques must satisfy the purpose of the sampling program, must be reasonably efficient at capturing the particles of interest, and must be compatible with the required counting or analytical methods. [15] The Hirst-type volumetric trap [16] has the potential to reliably obtain daily and up to bi-hourly data functioning continuously for one week, and it is the most frequently used pollen sampler worldwide, which has also been recommended by the European Aeroallergen Network. [17] Several studies have focused on the standardization of the methodology used with this air sampler; i.e., the sampling medium, the counting method used, [18-21] and the possibility to improve and maintain the quality of the network data it can provide. [22,23]

However, other samplers are frequently used at other sites or for specific applications, such as the Rotorod air sampler in America [24] and the Cour air sampler [25-27], which was specifically designed for crop forecasting. The Cour air sampler includes an exposed filter that cumulates particles until the filter is changed, so the periodicity of the data depends on the frequency of the filter changes. Several Cour air samplers are currently located in crop fields at sampling points far from populated areas, and therefore the filter-change frequency is usually determined to have datasets with a weekly discrete structure of the sampling periods, which can limit the usefulness of the data obtained. In this respect, an approximation of the daily data in historical databases based on the Cour method would improve the information they can provide in terms of our understanding of the phenological dates, the airborne pollination curves, and the allergen levels in the air. The ability to produce comparable daily data would also provide opportunities for the construction of models for predicting airborne pollen over large geographical areas. Therefore, in this study, we have investigated the design of a downscaling method for daily Cour air sampler data estimates.

This study focuses on olive pollen, as this pollen is one of the principal causes of pollinosis in the Mediterranean area, and it is also a good bio-indicator for crop forecasting. [28,29] We have therefore investigated the potential to validate the daily estimated data for airborne pollen detection using the Hirst-type spore trap. Both this and the Cour air sampler are based on impaction, but the Cour air sampler is a filter impact sampler and the Hirst air sampler is a volumetric suction trap. Hirst air samplers provide continuous aerobiological sampling that can easily define daily, or even bi-hourly, concentrations. [16] The structure of these data provides a considerable amount of information, particularly for floral phenology studies in anemophilous species, and for ecological impact studies and environmental health studies. Some previous comparative studies between Hirst and Cour air samplers have shown both quantitative and qualitative differences in the data obtained, with a higher spectrum of pollen taxa with the Cour air samplers and differences in pollen counts. [30-34] It has been observed that Cour air samplers usually capture a broader spectrum of pollen taxa, while Hirst air samplers usually capture a larger number of particles, although these aspects always depend on the characteristics of the pollen type.

As *Olea* pollen capture is also higher with Hirst air samplers, compared to Cour air samplers, and as olives are highly represented in the regional vegetation throughout the Mediterranean and their pollen is very allergenic, the present study aims to compare pollen data obtained using both of these methods. This study thus analyzes airborne *Olea* pollen data that were obtained using three pairs of Hirst air samplers and Cour air samplers placed together at three Tunisian sampling points, over a 3-year period (2009-2011). This study has three main objectives: 1. To compare the data obtained from the Hirst and Cour air sampling methods; 2. To design a downscaling method with which to estimate daily data from the Cour data obtained over longer sampling periods without the use of meteorological variables; and 3. To analyze the quality of the estimated daily data.

2. Material and methods

2.1 Study area and data quality.

Olea airborne pollen was recorded from 2009 to 2011 in three monitoring areas in Tunisia: Mornag (36º39'N, 10º16'E), Jemmel (35º38'N, 10º41'E) and Chaal.(34º34'N, 10º19'E) located in a altitude range between 30m and 100m. The climatic characteristics of the sampling points are shown in Table 1. For each site, one Hirst air sampler and one Cour air sampler were placed together (2 m apart), positioned at the same height above the ground. The time resolution for the impact in the Hirst database was bi-hourly during continuous monitoring, while the Cour database provides discrete monitoring, and the time resolution for the 'total concentrations' depended on the time between filter changes. In our database, the maximum resolution was 2 days, as the sampling periods were 48 h and 72 h.

Hirst and Cour air samplers are based on different basic principles (Figure 1). [16,25] The Hirst spore trap is a volumetric suction sampler that is based on an impaction process. It has a wind-vane tail to keep the 2.14-mm intake orifice facing the wind, and a rain shield to protect the orifice from precipitation. It needs to be provided with an external vacuum pump (10 L/min). Inside the housing containing the orifice, there is a transparent tape that is coated with an adhesive substance, which is wound around a drum that is moved with a clockwork mechanism at a rate of 2 mm/h. The particles in the air that is sampled are deposited by impaction on the adhesive tape, with a weekly capture capacity. Hirst data are presented as concentrations of pollen grains/m^3 of air, following the standardized methodology proposed by Galán et al., 2007. [22]

The Cour air sampler is also based on impaction, but the particles impact on a filter. The Cour air sampler consists of a metal support with a wind-vane tail and two filter holders (each of 400 cm^2). Although it does not have a suction pump, there is an anemometer nearby and the filter area measure provides an idea of the overall volume of air sampled. The filters are made of five layers of hydrophilic cotton gauze that are previously immersed in silicon and a thinner solution. This solution favors particle adherence, thus avoiding the loss of the captured pollen. The silicon also impedes bacterial and fungal growth during storage. These filters are usually changed weekly, and although they can be changed more frequently, the cost of the handling becomes higher. The efficiency of the sampler is more dependent on the wind speed and on the particle characteristics (e.g., density, size, form). Cour air sampler data are presented as concentrations of pollen grains/m^3 of air, following the standardized methodology proposed by Cour, 1974. [25]

2.2 Sampler comparisons and downscaling method

We initially compared data from both sampler types, as the total pollen grains from the air during the flowering period, in a seasonal index. Next, we designed a downscaling method to estimate the daily *Olea* pollen count from Cour air sampler data that extend over a longer sampling period. Then, we evaluated the performance of the estimated daily data for the Cour air samplers, comparing the data from both of these air sampler types as time series of daily pollen grains/m^3 air. The time series of daily pollen grains/m^3 air were analyzed by first applying a Lilliefors test, to test the normality of the daily Hirst data concentrations (DHirst) and the estimated daily Cour data concentrations (DEstimated). As the data differences between the DEstimated and the DHirst did not show normal distributions, they were checked using rank Wilcoxon tests. These tests were applied to ($DEstimated_n$ - $DEstimated_{n-1}$) *versus* ($DHirst_n$ - $DHirst_{n-1}$), to determine whether these two series behaved the same or differently, where n is the number of the specific day in the daily data time series. Finally, the Spearman correlations were calculated between DEstimated and DHirst. Wilcoxon tests and Spearman correlations are also useful to analyze differences in the development of time series and in the quality of the daily estimated Cour data, according to our method design.

3. Results

3.1 Comparison of methods

Table 2 gives the total *Olea* seasonal Pollen Index (PI) detected by both methods for each sampling site, with the PI defined as the sum of all of the *Olea* pollen concentrations recorded during the sampling period, with the total PI relating to the seasonal flowering periods for each year. Moreover, Figure 2 shows the percentages of *Olea* pollen in the air in terms of the total *Olea* seasonal PI, for the different geographic areas and study periods.

During the study period, the Cour air sampler provided a total *Olea* PI of 90,983 (Chaal, 30,496; Jemmel, 47,324; Mornag, 13,164), and the Hirst air sampler provided a total of *Olea* PI of 97,594 (Chaal, 33,364; Jemmel, 46,196; Mornag, 18,034). Overall, the Hirst air sampler captured 7.3% more pollen than the Cour air sampler. However, this was not a constant relationship between these two types of air samplers, as the PI was 9.4% greater with Hirst than Cour in Chaal, 2.3% less in Jemmel, and 37% greater in Mornag. Differences in these relationships can also be observed between the three study years, as shown in Figure 2. The greatest difference was seen during 2011 in the Mornag area, with the Hirst PI double that recorded for the Cour air sampler.

3.2 Downscaling method

An estimation method was designed to estimate the daily volumetric concentrations of airborne *Olea* pollen that would be detected using the Cour air samplers. The downscaling method uses the Cour data that was obtained over a longer sampling period (without the use of meteorological variables) to estimate the daily data. The variable that represents the data obtained with the Cour air sampler is called the 'DCour', while the variable that represents the data collected with the Hirst air sampler is the 'DHirst'; further, the variable representing the daily data that are estimated from the DCour air sampling is called 'DEstimated'. Here, the DEstimated was calculated from DCour by dividing each DCour into several DEstimated (as shown in Equation (1)), as each DCour includes the total airborne particles recorded for different numbers of days, which depended on the inter-sampling periods.

$$DCour_z = DEstimated_{1,z} + DEstimated_{2,z} + DEstimated_{3,z} + \cdots DEstimated_{j,z} \tag{1}$$

where z is the order number of DCour$z$ in the Cour data time series and j is the order number of the DEstimated in the daily Cour data time series estimated from a specific DCour. When calculating DEstimated, it is necessary to bear several factors in mind: (i) the inter-sampling period that lapsed between DCour$z-1$ and DCour$z$; (ii) the theoretical trend of the estimated data between DCour$z-1$ and DCour$z$; and (iii) the theoretical slope of the estimated data between DCour$z-1$ and DCour$z$.

Based on Equation (1), when the number of days between DCour$z-1$ and DCour$z$ is i, the value of i of the DEstimated data must be estimated, as DCour$z$ includes the information of the total amount of airborne pollen for i days. We therefore defined the variable ST, as the number of days that lapsed between DCour$z-1$ and DCour$z$. In the Equations, the value of ST is termed as i.

DEstimatedj,z was designed as the multiplication of DCour$z$ and a certain factor, which we have called A, as expressed in Equation (2), such that Equation (3) applies.

$$DEstimated_{i,j,z} = A_{i,j,z} * DCour_z \tag{2}$$

where $A_{i,j,z}$ is the factor applied to DCour$z$ for the calculation of DEstimatedi,j,z.

$$1 = \begin{cases} A_{1,1,z} & if \quad ST = 1 \\ A_{2,1,z} + A_{2,2,z} & if \quad ST = 2 \\ \quad \dots & \\ A_{i,1,z} + A_{i,2,z} + \cdots A_{i,j,z} & if \quad ST - i \end{cases}$$

(3)

When DCour$z$ = DCour$z$-1, A is calculated according to Equation (4), DEstimated is calculated according to Equation (5), and DCour is calculated according to Equation (6):

$$\mathrm{A}_z = \left(\frac{1}{ST_z}\right)$$

(4)

$$DEstimated_{i,j,z} = \left(\frac{1}{i}\right) * \ DCour_z$$

(5)

$$DCour_z = \left(\frac{1}{i}\right)_1 * DCour_z + \left(\frac{1}{i}\right)_2 * DCour_z + \cdots \left(\frac{1}{i}\right)_j * DCour_z$$

(6)

where j is the number of days that lapsed from DCour$z$-1 +1 to DCour$z$, and i is the value of STz. But when DCour$z$ ≠ DCour$z$-1, it is necessary take into account the theoretical trend and the theoretical slope when calculating DEstimated.

The theoretical trend of the estimated data between DCour$z$-1 and DCour$z$ can be positive or negative. It was assumed that the theoretical trend of DEstimated$z$ is the same as the real trend between $\frac{DCour_{z-1}}{ST_{z-1}}$ and $\frac{DCour_z}{ST_z}$. We therefore developed a new variable, termed here as B (as shown in Equation (7)), such that $B \subset [0,\infty)$.

$$B_z = \frac{\left(\frac{DCour_z}{ST_z}\right)}{\left(\frac{DCour_{z-1}}{ST_{z-1}}\right)} * 100 \tag{7}$$

Here, B includes information about the theoretical trend of DEstimated*z*, as is shown in Equation (8):

$$if\ B_z \begin{cases} > 100; \left(\frac{DCour_z}{ST_z}\right) > \left(\frac{DCour_{z-1}}{ST_{z-1}}\right); Positive\ trend \\ < 100; \left(\frac{DCour_z}{ST_z}\right) < \left(\frac{DCour_{z-1}}{ST_{z-1}}\right); Negative\ trend \end{cases} \tag{8}$$

When $B \neq 100$, the slope must also be taken into account when calculating A. It was assumed that the theoretical slope of Az is the same as the real slope of Bz, as the daily pollen time series usually presents a continuous pattern (Domínguez-Vilches et al., 1993). The day of DCour*z* is defined as the last day of the sampling period of DCour*z*. Dmax is used as the day between DCour*z-1* and DCour*z* with, theoretically, the largest amount of pollen. We also termed Dmin as the day between DCour*z-1* and DCour*z* with, theoretically, the lowest amount of pollen. In this downscaling method, there are only two possible days that can be assigned as Dmax or Dmin, and these potential days are the dates of DCour*z-1*+1 and DCour*z*. Dmax and Dmin are calculated using the following Equations (9) and (10):

$$Dmax_z = \begin{cases} \text{Day of DCour}_{z-1} + 1 \text{ if } B_z < 100 \\ \text{Day of DCour}_z \text{ if } B_z > 100 \end{cases} \tag{9}$$

$$Dmin_z = \begin{cases} \text{Day of DCour}_{z-1} + 1 \text{ if } B_z > 100 \\ \text{Day of DCour}_z \text{ if } B_z < 100 \end{cases} \tag{10}$$

Next, it is necessary to calculate the *Az* values used to calculate DEstimated*z* in Dmax and DEstimated*z* in Dmin, giving *A* of Dmax and *A* of Dmin. *A* of Dmax and *A* of Dmin are related to *B* in an asymptotic manner. Where *B* tends towards infinity, from *B* = 100, *A* of Dmax tends towards a maximum value, and *A* of Dmin tends towards a minimum value; and where *B* tends towards 0, from *B* = 100, *A* of Dmax also tends towards a maximum value and *A* of Dmin also tends towards a minimum value. A new variable termed *B2* was therefore developed, which was calculated according to Equation (11), such that $B2 \subset [100,\infty)$.

$$B2 = \begin{cases} B & if \quad B > 100\% \\ B & if \quad B = 100\% \\ \dfrac{\left(\dfrac{DCour_{z-1}}{ST_{z-1}}\right)}{\left(\dfrac{DCour_z}{ST_z}\right)}\% & if \quad B < 100\% \end{cases} \tag{11}$$

A of Dmax and *A* of Dmin are functions of *B2*: f(*B2*). *A* of Dmax is a function of *B2* according to Equations (12) and (13). Equation (14) therefore meets all of the conditions expressed in Equations (12) and (13), and so the downscaling method is based on Equation (14).

$$\lim_{B2\to\infty} f(B2) = Maximum\ value\ of\ A \quad (12)$$

$$f(100) = \left(\frac{100}{ST_z}\right) \quad (13)$$

$$A = f(B2) = \frac{\alpha}{B2} + \beta \quad (14)$$

where β is a constant that is dependent on the maximum value that can be taken by A of Dmax and α is another constant that is dependent on the minimum value that can be taken by A of Dmax, the A value when B = 100. A of Dmin is calculated in the same way as A of Dmax. The constants were calculated using DHirst, by optimizing the root mean squared error between DHirst and DEstimated. The theoretical variations in the potential volumetric concentrations of the airborne pollen signify that the pollen captured daily by the Cour air sampler must be related to the real variations in the volumetric concentrations captured daily by the Hirst air sampler.

Figure 3 shows the possible values that A can take in our scenario, where ST $\subset$ [2, 3]. Note that the values of A asymptotically approach the maximum value of 'A of Dmax' and the minimum value of 'A of Dmin' when $B2$ tends towards infinity. Equation (15) shows the optimized values of these constants.

$$A = \begin{cases} \text{if } ST = 2 \begin{cases} A\ of\ Dmax = -\dfrac{3000}{B2} + \dfrac{1000}{50} \\ A\ of\ Dmin = 100 + \left(\dfrac{3000}{B2} + \dfrac{1000}{50}\right) \end{cases} \\ \text{if } ST = 3 \begin{cases} A\ of\ Dmax = -\dfrac{667}{B2} + \dfrac{2000}{50} \\ A\ of\ Dmed = \left(\dfrac{100}{3}\right) \\ A\ of\ Dmin = 100 - \left(\left(\dfrac{100}{3}\right) - \left(\dfrac{667}{B2} + \dfrac{2000}{50}\right)\right) \end{cases} \end{cases} \tag{15}$$

3.3 Downscaling method confirmation

Figures 4-6 show the daily olive pollen content in the air through the yearly flowering seasons, as provided by the Hirst air samplers and the Cour air samplers, structured in discrete sampling periods of 48 h and 72 h. These figures also show the interpolated daily estimated data obtained with the designed method.

Table 3 shows the data for the statistical tests that were performed with the daily data series of the Hirst air samplers and the interpolated daily data series of the Cour air samplers. As is shown, the Wilcoxon tests did not define significant differences between the change rates of either of the series. There is also high correlation in all cases, which signifies that both of these time series evolved in the same way. Thus, these tests show that both of these series evolved over time in a similar manner, which demonstrates the effectiveness of the downscaling method. However, Figures 4 and 6 show that the data provided by each of the pollen traps did not always maintain a constant ratio.

4. Discussion

Several studies have compared both quantitative and qualitative airborne pollen data detected by Hirst and Cour air samplers. In general, these studies have indicated that from a qualitative point of view, in most cases a greater number of taxa are detected with the Cour trap. [30,32,34]

From a quantitative point of view, previous studies have agreed that there are some differences between the Hirst and Cour air sampler methods, although this also depends on the pollen type and the sampling environment, as meteorological variables can differently affect each one of these sampling techniques. [30,32-34] In the case of *Olea*, previous studies have argued that there is a higher PI with Hirst air samplers than with Cour air samplers, which is in general agreement with our data. However, the differences that we have observed here are smaller than those that might be expected according to the previous literature. This can be explained on the basis that in the present study, the maximum sampling period used was 3 days, while in previous studies, Cour monitoring has usually been at 1-week intervals, which would indeed produce an increasing clogging effect of the Cour filters.

At the same time, a constant mathematical relationship between these data obtained by these two types of air samplers cannot be provided; i.e., in some years, a higher pollen content in the air was detected with the Cour air samplers, and in others with the Hirst air samplers. These differences can probably be explained by the different processes on which these methods are based and on external agents, such as wind, temperature and/or precipitation, among others, which can affect them differently. The Hirst air sampler has a suction pump that always sucks air with a capacity of 10 L/min in the prevailing direction of the wind, and while the Cour air sampler also detects more particles in the wind direction, its capture capacity depends on the wind speed, as the particle levels in the air will not be equal during all of these processes. Thus the Cour air sampler can be over-representative of the concentrations present when the wind speed is high, and can be under-representative when the wind speed is low. This error is allowed for by our downscaling method. For this reason, the aerobiological method should always be reported along with the volumetric data obtained.

On the other hand, the impaction surfaces of these two air sampler types are differently exposed to other weather events, such as rainfall or extreme temperatures. Indeed, potentially, the downscaling method can be improved with the use of the full weather parameters and by considering extreme events. However, in such a case, the effectiveness of this downscaling method for use with other Cour databases would diminish, as it would then be more closely linked to the availability of the full meteorological data.

Therefore, although the data derived from these two types of air trap are not precisely the same, our results show that these data are generally comparable for uses in studies that do not require extreme precision, such as for air allergenicity analyses based on a categorical focus, as was argued by Belmonte et al., [33] or for use as agricultural tools, as shown by Ribeiro et al.. [35]

There have been other attempts to define a mathematical relationship between Hirst and Cour air sampler data, particularly by comparing data relating to the total weekly amounts of airborne pollen. Duran and Comtois (1989) [30] obtained a relationship that was generic for all taxa, which indicated that *Hirst = 4 × Cour*, although other studies have argued that this relationship will depend on the taxa studied. In the case of the olive, Tomás et al. (1997) [32] defined this as *Hirst weekly data = 2.03 × Cour weekly data*, while Belmonte et al. (2000) [33] showed an averaged value as *Hirst = 1.21 × Cour*. This last study proposed a method relating to categorical transformations, which is very useful for investigations related to pollinosis, although their categorical transformation does not function for other kinds of studies.

Our method for the daily data downscaling is here shown to be effective, and to allow better exploitation of the potential of the Cour air sampler, although it remains important to bear in mind the limitations to the quality of the interpolated data. [36] This method is tested here for two-day and three-day Cour data of the *Olea* pollen type, and it will also be necessary to test its efficiency for weekly Cour data and for other pollen taxa.

These data estimation methods have been extensively studied and analyzed across many scientific and technological fields [37-41], and downscaling studies have been shown to have a myriad of purposes, such as for geospatial downscaling [38] or climatic downscaling. [42,43] The present study shows the design of a new method with which to estimate the daily data using a nonlinear approach. Indeed, this might even be useful as a basis for improvements to estimation techniques in other scientific fields, whenever the intention is to estimate continuous data.

5. Conclusions

Quantitative differences were detected between data provided by Hirst air samplers and Cour air samplers, and these did not allow the formulation of a constant relationship between these two air sampler types. The effectiveness of the downscaling method designed here is demonstrated, and this allows the potential of Cour air sampler data series to be better exploited. However, it remains necessary to consider the limitations to and the quality of the interpolated data.

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FIGURE CAPTIONS

Figure 1. Pollen samplers used in these aerobiological studies. (A) Cour pollen trap; (B, C) Volumetric pollen traps based on the Hirst model, monitoring a known air volume per minute.

Figure 2. Total seasonal *Olea* pollen/m^3 of air using the Hirst air samplers (H.; unshaded) and the Cour air samplers (C.; shaded) in each of the monitoring areas over the three study years.

Figure 3. *A*(x100) behavior with regard to *B2*. The asymptotes show the maximum value of *A* and the minimum value of *A*.

Figure 4. Relationships between the daily Hirst data, the discrete Cour data, and the estimated daily Cour data through the seasonal flowering periods over each study year for Mornag.

Figure 5. Relationships between the daily Hirst data, the discrete Cour data, and the estimated daily Cour data through the seasonal flowering periods over each study year for Jemmel.

Figure 6. Relationships between the daily Hirst data, the discrete Cour data, and the estimated daily Cour data through the seasonal flowering periods over each study year for Chaal.

Table 1. Monthly rainfall and daily temperature data for each of the aerobiological sampling points, averaged over the period from 1993 to 2011 (standard deviation in brackets). JFM, January, February, March; AMJ, April, May, June; JlAS, July, August, September; OND, October, November, December.

Olive growth area	Rainfall (mm)				Temperature (°C)			
	JFM	AMJ	JlAS	OND	JFM	AMJ	JlAS	OND
Mornag	49.9 (32.2)	27 (29.1)	19.5 (45.1)	49.7 (40.96)	12.7 (2.9)	21.1 (4.4)	27.3 (2.9)	17.1 (4.4)
Jemmel	27.6 (42.4)	24 (31.7)	29.1 (30)	22.6 (28.2)	19.9 (5.9)	19.7 (5.9)	20.2 (6.3)	20.53 (6)
Chaal	17.2 (27.5)	18 (22.5)	18.6 (23.2)	14.8 (23.8)	19.5 (6.2)	19.7 (6.1)	20.2 (6.4)	20.3 (6)

Table 2. *Olea* Pollen Index recorded during the study period for the different study areas.

Season	Pollen Index					
	Mornag		Jemmel		Chaal	
	Hirst	Cour	Hirst	Cour	Hirst	Cour
2009	2,794	4,648	33,069	34,863	14,010	9,438
2010	2,131	2,106	6,708	6,094	11,756	14,618
2011	13,108	6,410	6,418	6,367	7,598	6,440

Table 3. Rank Wilcoxon test and Spearman correlations between the daily Hirst data and the estimated daily Cour data.

Zone	Wilcoxon sig.	Spearman correlation
Mornag	0.745	0.797**
Jemmel	0.833	0.882**
Chaal	0.864	0.641**

**, $P < 0.05$

Figure 1.

Figure 2.

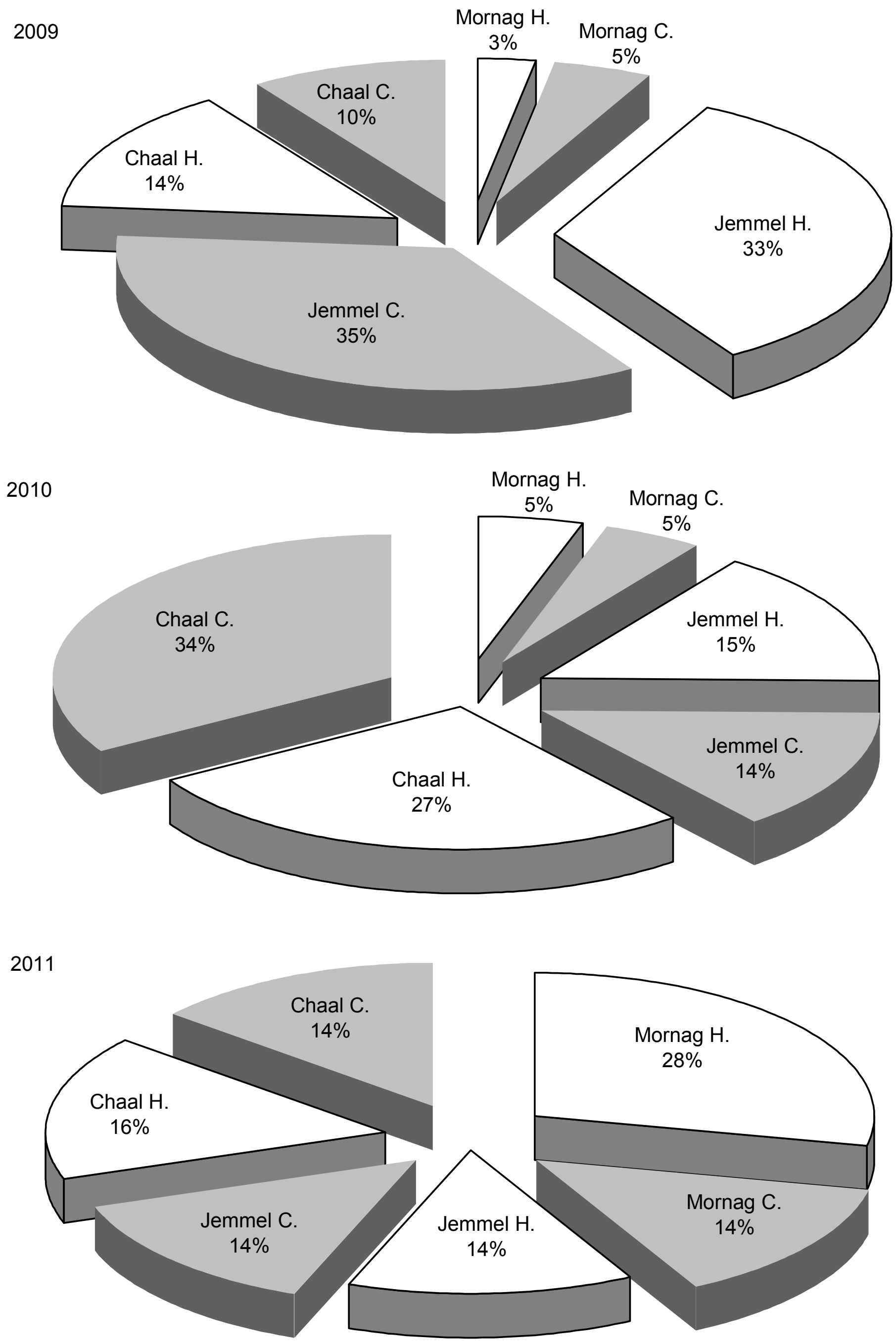

2009
Mornag H.
3%
Mornag C.
5%
Chaal C.
10%
Chaal H.
14%
Jemmel H.
33%
Jemmel C.
35%
2010
Mornag H.
5%
Mornag C.
5%
Chaal C.
34%
Jemmel H.
15%
Jemmel C.
14%
Chaal H.
27%
2011
Chaal C.
14%
Mornag H.
28%
Chaal H.
16%
Jemmel C.
14%
Jemmel H.
14%
Mornag C.
14%

Figure 3.

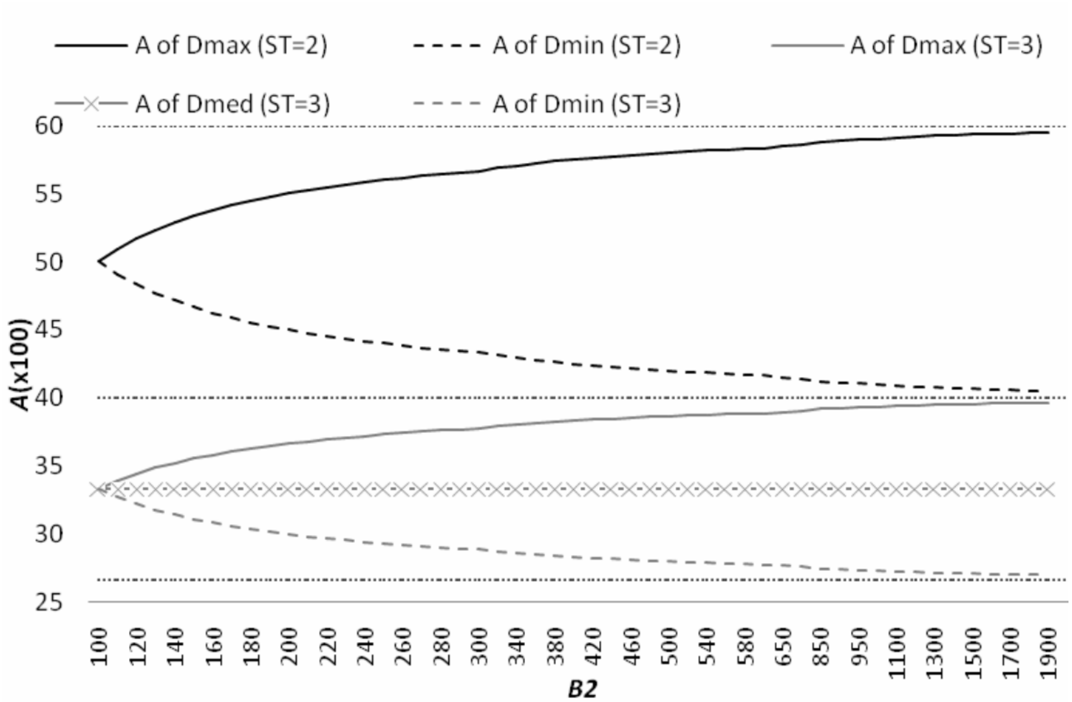

A of Dmax (ST=2)
A of Dmin (ST=2)
A of Dmax (ST=3)
A of Dmed (ST=3)
A of Dmin (ST=3)
A(x100)
60
55
50
45
40
35
30
25
100 120 140 160 180 200 220 240 260 280 300 340 380 420 460 500 540 580 650 850 950 1100 1300 1500 1700 1900
B2

Figure 4.

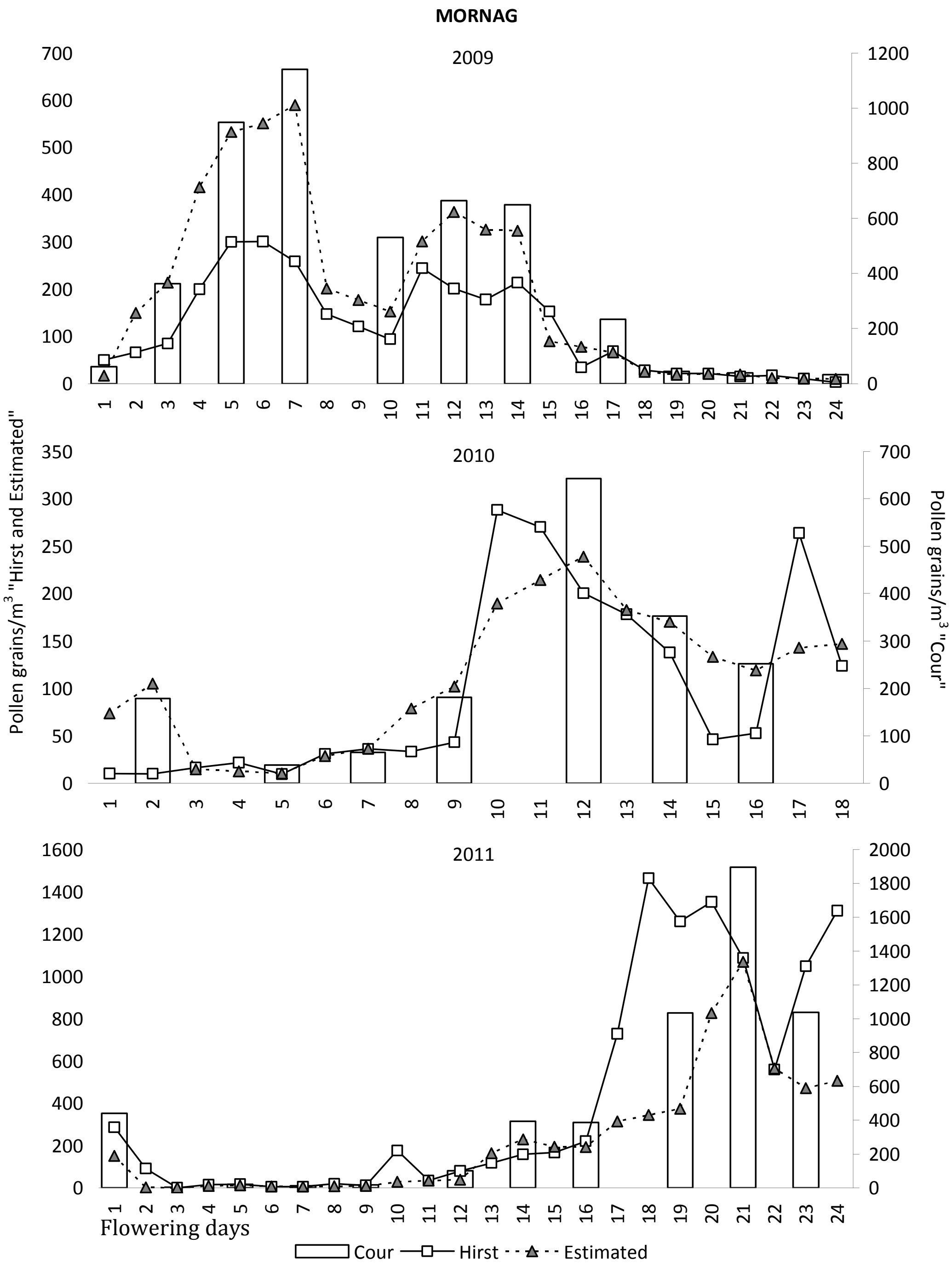
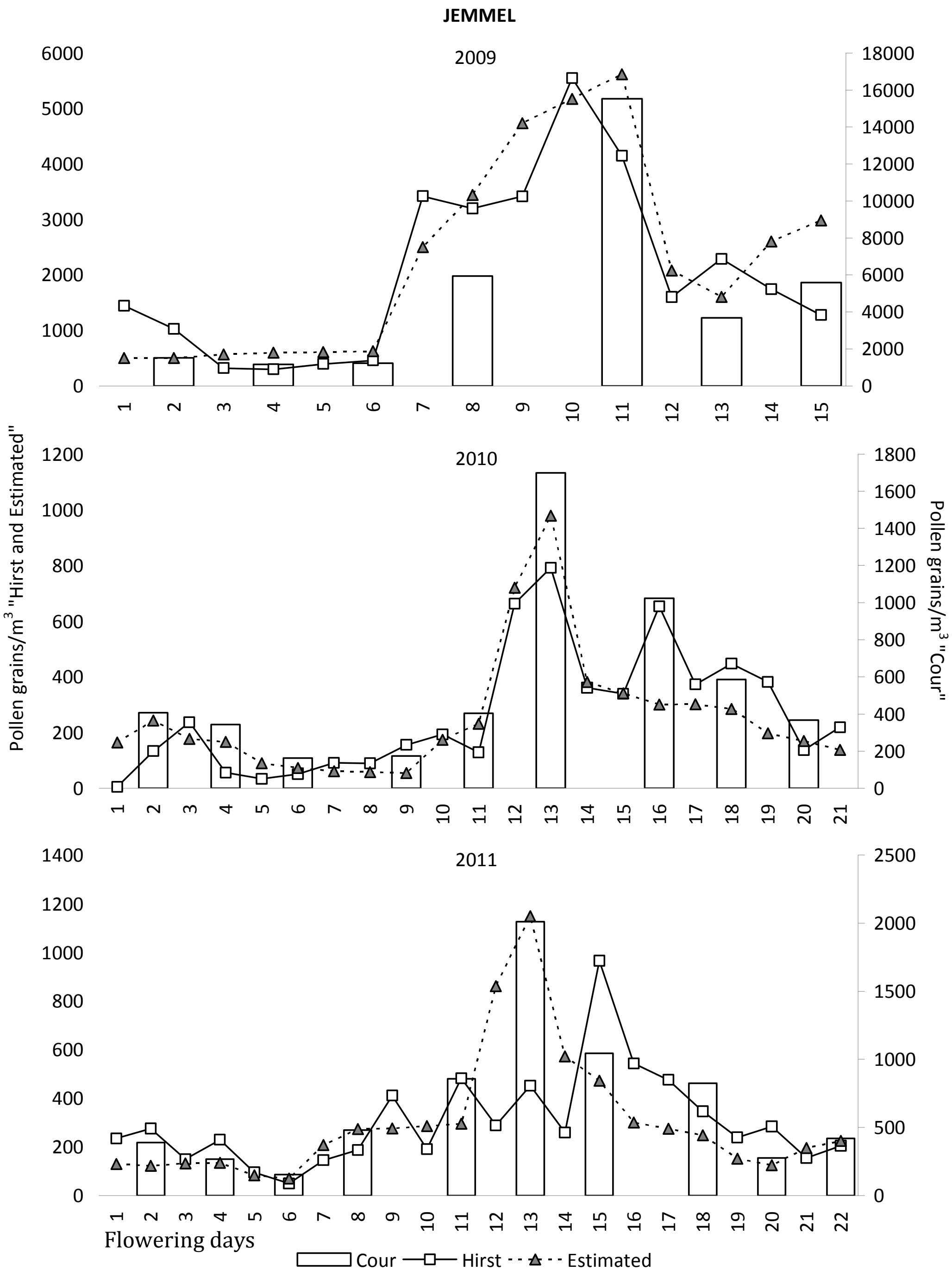
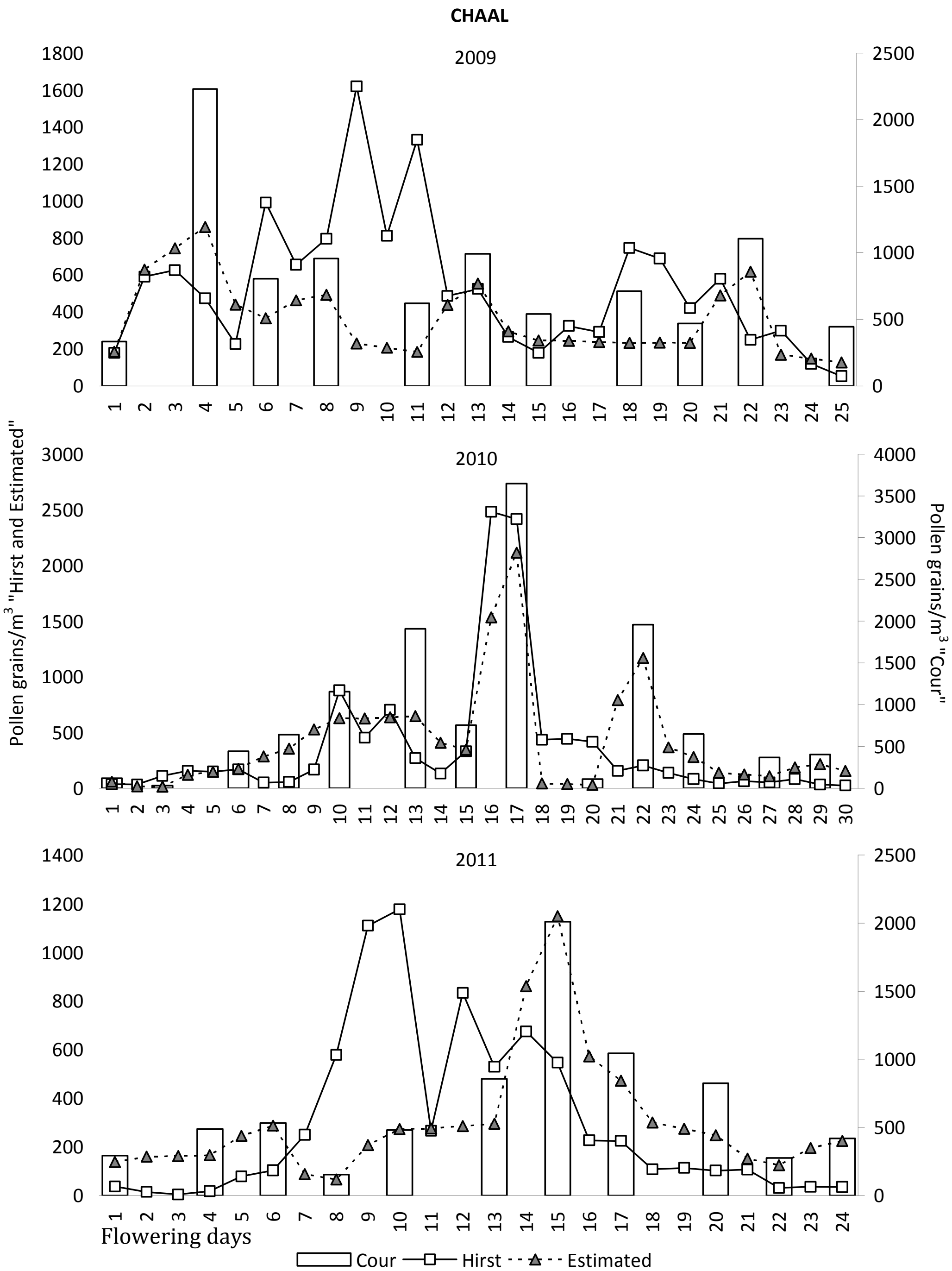

MORNAG
2009
2010
2011
Pollen grains/m^3 "Hirst and Estimated"
Pollen grains/m^3 "Cour"
Flowering days
Cour
Hirst
Estimated

Figure 5.


JEMMEL
2009
2010
2011
Pollen grains/m3 "Hirst and Estimated"
Pollen grains/m3 "Cour"
Flowering days
Cour
Hirst
Estimated

709 **Figure 6.**


CHAAL
2009
2010
2011
Pollen grains/m^3 "Hirst and Estimated"
Pollen grains/m^3 "Cour"
Flowering days
Cour
Hirst
Estimated