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Expanding dendrochronology to palms: A Bayesian approach to the visual estimate of a palm tree age in urban and natural spaces

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ABSTRACT

The age of trees and palms is fundamental with respect to their probability of survival, the quality and quantity of their production and their value as unique specimens. Determining these ages is necessary in different contexts (natural, forest, agriculture, urban trees and landscaping). Dendrochronology makes it possible to determine the age of trees, but for palms (Arecaceae) it is still lacking. Here we present and use a method based on the study of whole palm tree images and linear regression of stem/crown ratio and age in years, created with individuals of known age, and posterior probability distribution functions using Bayesian and Monte Carlo methods. This methodology is applicable to the estimate of adult palm individuals of different Arecaceae genera that reach the maximum dimensions of crown once became adult, provided an ensemble of individuals with known age is available for comparison. This approach is here applied to the estimation of the age of Canary Islands palm trees. The proposed methodology shows that the age in years of a Canary Islands palm tree is 28.33 × stipe (S)/crown (C) ratio + 7.03 ± s. The application of the methodology allowed the discovery of a dispersal event around 1840–1845, unknown until now, and revealed two palms from Tenoya (Gran Canaria, Spain) as the oldest known living Canary Islands palms, with an estimated age of over three hundred years.

1. Introduction

Dendrochronology developed throughout the 20th century. Tree ring dating was the only accurate method of determining the age of trees until the 1950s when the radiocarbon dating method was developed, which was initially calibrated by tree ring measurements [7]. However, both methods are hardly applicable to palms, given the peculiarity of their structure and growth patterns: lack of aboveground stem permanently or during part of their life [19], coincidence of primary apical and "secondary" stem lengthening [26], and lack of growth rings in the above ground stems.

Additionally, the problem with radiocarbon dating of recent plant materials, less than 500 years old, is that it tend to overestimate their age in a range between 50 and 250 years, something already detected by Ralph et al. [24] comparing with dendro-chronologically dated wood samples. The inherent limitations in the conversion of radiocarbon dates to calendar ages [13], reduces the chances of establishing an age for a tree with a low degree of uncertainty.

Some monocotyledonous tree like species such as *Dracaena cinnabari* Balf.f. (Asparagaceae) show annual growth of trunk thickness but no recognizable rings. The 10-year radial stem increment and diameter at breast height obtained in 2011 in natural populations of the species from Socotra (Yemen) served to Bauerová et al. [6] as a basis for the linear model from which the equations for the age calculation were derived. According to the fit model, the age was estimated to be between 111 and 672 years, but with a high degree of uncertainty. Other methods for age

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estimate in this species, previously proposed, are indirect and based in the development of crown peripheral branching orders [2] and flowering patterns [3].

Palms become tall trees entirely by primary growth in a way that limits their growth habit, i.e. stem girth size, but not their capacity for continued stem development (lengthening). They achieve massive primary stature because of distinctive features of leaf development, stem vasculature and anatomical properties [40].

The need to determine the age of palm trees (Arecaceae) responds to very diverse conditions ranging from the designation of singular unique specimens chosen for their longevity [17,46], the assessment of the historical relevance of a group of palm trees in a garden context, the evaluation of survival probability for palm crops of industrial or food interest [39] or the urgency of replanting a specific African oil palm (*Elaeis guineensis* Jacq.) [15].

The evidence that the length of the trunk of palm trees is proportional to their age has been known since ancient times. The linear regression obtained by Jahromi et al. [16] for the common date palm (*Phoenix dactylifera* L.) shows that date palms grow 0.26 m per year, on average. On the island of La Gomera, the sap of palm trees (*P. canariensis* H.Wildpret) is traditionally extracted to produce the so-called *Miel de Palma* (Palm Honey). In the process of extracting the sap, the farmers cut the heart of the palm tree following an ancestral procedure. When as much sap as possible is extracted from a specimen, the palm tree is left to "rest" without being exploited for 5–6 years. During this time, the palm tree puts out new leaves and the specimen continues to grow. It has been proven that the growth of these specimens during the 5–6 years of rest reaches around 1 or 1.5 m, which means a growth of between 0.2 and 0.3 m per year, since a ring is marked in the place where the sap was extracted.

Palm height is the vertical distance between the base of the palm tree and the highest tip of the leaves that form the crown and is difficult to measure accurately. In the case of leaning palm trees the stipe or trunk length may be greater than the height of the palm tree.

The problem in many cases is the measurement of height in meters, which requires the use of graduated scales, tape measures, clinometers, trigonometric calculations or specialized optical and electronic instruments [14]. This is why we will focus on the visual assessment of allometric relationships. This is based on the measurements of different parts of the palm tree that can be observed in images independently of the absolute values of the variables considered. The use of visual estimate of palm parameters is not new, Blair et al. [8] successfully approached the visual palm health assessment.

Tan et al. [39] and Vadivelu et al. [42], working with large stands of palm trees, used remote sensing techniques to estimate the age of African oil palm trees. However, our focus is on the study of individual specimens.

Our objectives focus on developing a single method to routinely estimate the age of the Canary Island palm tree based on the direct observation or the analysis of images. We are especially interested in one method allowing us to express the degree of uncertainty in the estimate.

We intend to experimentally test the new method in several practical cases such as the identification of the oldest specimens in the Canary Islands. We also intend to determine the oldest specimens cultivated outside the Canary Islands and their relationship with the successive relevant events of dissemination of seeds and plants of the species from the Canary Islands to the rest of the world. *Phoenix* (Arecaceae) is a genus of palms of economic and cultural relevance, whose morphological and molecular diversity are relatively well studied [5,23,29]. During the past 150 years, the Canary Island date palm has found widespread use as an ornamental in public and private spaces across the globe notably in urban contexts [18,36,37]. In the case of the Canary Island date palm, determining the age, even approximately, of wild specimens can help in the establishment of conservation protocols for individuals and communities in natural spaces [20,35]. But in the context of gardening it becomes even more useful as it can help to reduce the incertitude of age in certain plantations and to determine the first waves of introduction of this species in cultivation outside its area of origin in the Canary Islands and bridges the gap in the available evidence [36,49].

2. Materials and methods

The variables considered are the length of the trunk or stipe of the palm tree (s in Fig. 1A), from ground level to the base of the crown of leaves, measured on an undistorted image and, on the same image, the height of the crown (c in Fig. 1A), measured from the apical end of the stipe or base of the crown to the apex of the crown, defined by the end of the erect or suberect leaf that is furthest from the base. Given that the fully developed crown follows approximately the sphere, c is measured on the upper vertical radius of crown. The stem-crown transition (Fig. 1B) is relatively easy to determine in heavily cropped crowns, where older leaves are removed. The stem-root transition determines the base of the stem or stipe (Fig. 1C).

As a starting point for computing the regression, we have analyzed a set of 68 Canarian palm trees (Table 1) for which the date and approximate age at the time of planting is known for all palm trees and images with known date are available so that the age of the palm tree at the time the image was taken at a sufficient distance from the palm tree to avoid distortions caused by perspective or the curvature of the lenses. To avoid distortions in perspective the optimal distance is about halfway the height of the subject [1], in our case the palm tree.

The procedure followed is the construction of a linear regression between the age of the palm tree, considering those of well-known age, and the values of their stipe/crown ratio (Table 1). Several methods have been used here to construct the linear regression: a, least squares, b, Zellner's Bayesian simple univariate normal linear regression and c, the Bayesian method provided by Stan (see below). We worked using R Studio, within the R framework. R is a free software environment for statistical computing and graphics [31]. The RStudio [34] integrated development environment (IDE) is a set of tools created to improve productivity in the R and Python languages. The tools are available at Cran R Project [12].

The R Stats Package [32] furnished *lm* that is used to fit linear models, including multivariate ones. It can be used to carry out regression, single stratum analysis of variance and analysis of covariance. We use *lm* to build a classical least squares regression model in which normality of residuals is assumed. Then we plot the data and the regression line. After introducing one S/C (Stipe/Crown coefficients, S/C), value we create a data frame of age values and their corresponding probability densities, and a *ggplot*® with the predicted value and probability density function.

In parallel, based on the approach of Zellner [48], we specifically designed the script in R for the Bayesian approach to linear regression. In the simple univariate normal linear regression model, we have one random variable (hence the term "univariate"), the "dependent" variable (Stipe/Crown coefficients, S/C), whose variation is to be explained, at least in part, by the variation of another variable, the "independent" variable (age of the palm tree, abbreviated as age). Formally, with the dependent variable (S/C), denoted by y, and the independent variable (age) denoted by x, we have the following relationship (1):

$$y_i = \beta_1 + \beta_2 \quad x_{i+} + \mu_i, i = 1, 2, \ldots, n \tag{1}$$

where.

y_i = ith observation on the dependent variable S/C,

x_i = ith observation on the independent variable age (and we assume these, for i = 1 to i = n, are fixed no stochastic variables),

μ_i = ith unobserved value of the random disturbance or error variable (assuming, for i = 1 to n, these are normally and independently distributed, each with zero mean and common variance σ^2), and.

$\beta_1 and \beta_2$ = regression parameters, namely, the "intercept" and "slope coefficient", respectively.

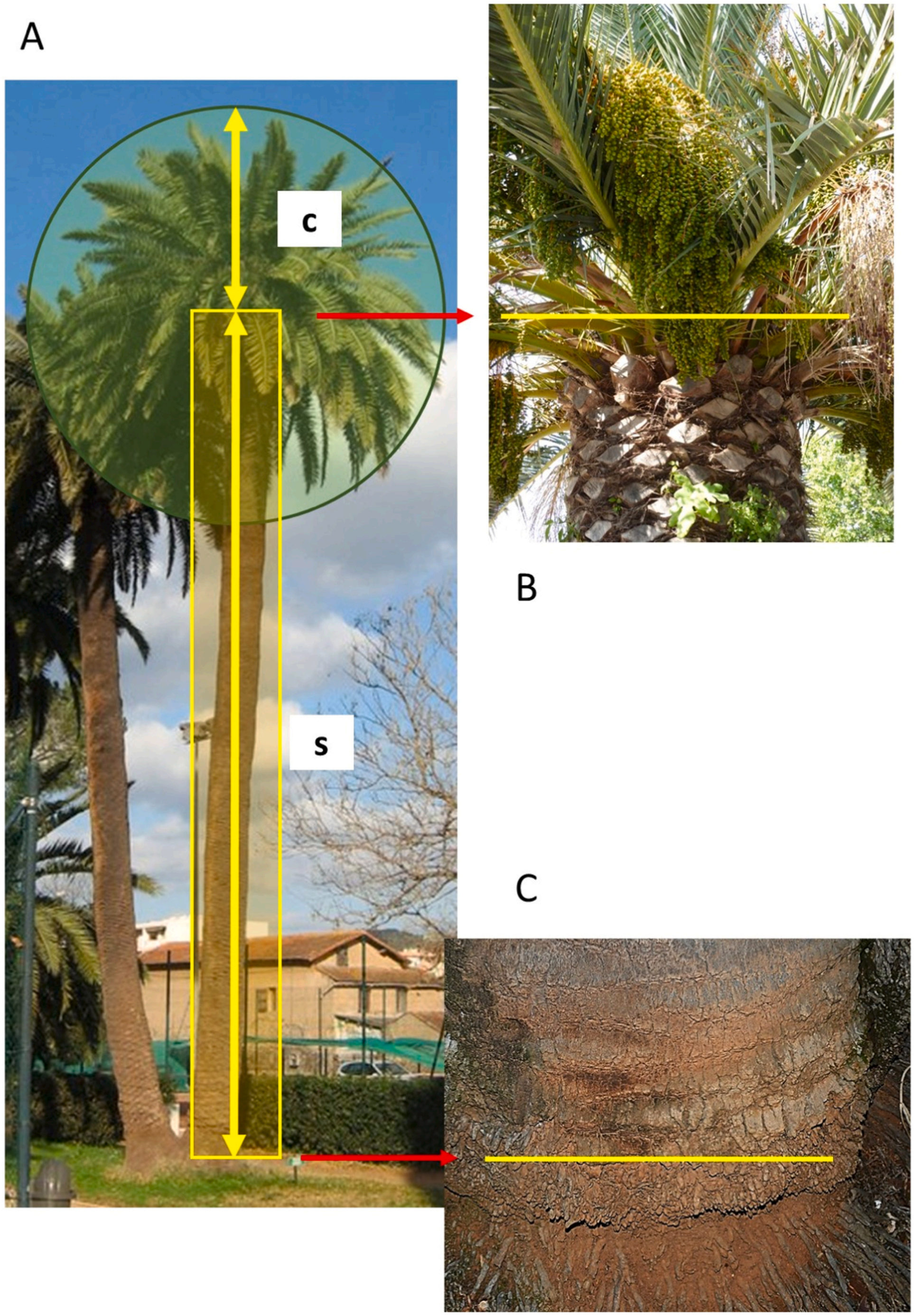

Fig. 1. Guide for palm stem and crown measurement. A General view, s, length of stem, c, upper vertical radius of crown. B, stem-crown transition. C, stem-root transition.

With the following joint distribution function (2):

$$p(y|x,\beta_1,\beta_2,\sigma)\propto\frac{1}{\sigma^n}\quad e^{[-\frac{1}{2\sigma^2}\sum_1^n (y_i-\beta_1-\beta_2x_i)^2]} \tag{2}$$

The expression in (2), viewed as a function of the parameters β_1, β_2, and σ, is the likelihood function to be combined with our prior pdf (probability distribution function) for the parameters that in this case is diffuse.

Then the joint posterior pdf for β_1, β_2, and σ, with a diffuse prior pdf, is given by (3):

$$p(\beta_1,\beta_2,\sigma|y,x)\propto\frac{1}{\sigma^{n+1}}\quad e^{[-\frac{1}{2\sigma^2}\sum_1^n (y_i-\beta_1-\beta_2x_i)^2]} \tag{3}$$

Statistics calculated are: x mean, y mean, x^2 mean, x variance, y variance, y standard deviation, and x,y covariance. Using these statistics and a series of functions derived from the above, the posterior values $\widehat{\beta}_1$ and $\widehat{\beta}_2$, the "intercept" and "slope coefficient'' respectively, are obtained.

Finally, we used RStan [33] (the R interface to Stan) and Stan [38]. Stan is a C+ + library for Bayesian inference using the No-U-Turn sampler (a variant of Hamiltonian Monte Carlo) [38]. The model predicts the variable S/C based on the predictor age using a normal prior

Table 1
Phoenix canariensis reference palm trees with known planting date. Abbreviation: lm, linear model; (*), years.

Locality and date of images	S/C	Age estimated lm (*)	Age (*)	Date Planting
Arias de la Noceda Aviles (Spain)	4.16	122	132	1883
Beverly Hills Los Ángeles ACP (USA)	4.94	144	123	1907
Beverly Hills Los Ángeles_1931a	1.62	51	38	1907
Beverly Hills Los Ángeles_1931b	1.31	42	38	1907
Beverly Hills Los Ángeles_1922a	1.21	39	36	1907
Beverly Hills Los Ángeles_1922b	1.28	41	36	1907
Caldas de Reis 2010	3.78	112	110	1905
Caldas de Reis 1962	2.4	73	67	1910
Camino Largo 1964d	2.8	84	68	1907
Camino Largo 1907–10	0.00	5	8	1907
Camino Largo 1920	0.33	14	18	1907
Camino Largo 1925a	0.40	16	18	1907
Camino Largo 1925b	0.34	15	18	1907
Camino Largo 1925c	0.36	15	18	1907
Camino Largo 1932a	0.47	18	24	1907
Camino Largo 1932b	0.43	17	24	1907
Camino Largo 1932c	0.50	19	24	1907
Camino Largo 1932d	0.61	22	24	1907
Camino Largo 1945a	1.78	55	48	1907
Camino Largo 1945b	1.88	58	48	1907
Camino Largo 1964a	2.49	75	70	1907
Camino Largo 1964b	2.61	78	70	1907
Camino Largo 1964c	2.69	81	70	1907
Campus Espinardo 2017	1.2	39	40	1982
Casa de las Palmeras Colombres	3.41	101	134	1880
Casa de Piedra Colombres	4	118	114	1900
Casa de Piedra Colombres	4.2	123	114	1900
Casa Ramón Asenjo Luarca	3.5	104	105	1910
Casas Helgueras en Noriega	3	90	108	1910
Casona de la Fuente Llanes	3.18	95	95	1920
Chalet Azul Llanes	4	118	120	1895
Chalet Francés Colunga	4.27	125	125	1890
El Xalé Oles Villaviciosa	3.09	92	107	1909
La Blocarde Foussat Hyeres 1911a	1.1	36	41	1875
La Blocarde Foussat Hyeres 1911b	1.05	35	41	1875
Las Palmeras Bailén 2013a	2.03	62	81	1935
Las Palmeras Bailén 2013b	2.05	63	81	1935
Las Palmeras Bailén 2013c	2.06	63	81	1935
Las Palmeras Bailén 2013d	2.25	68	81	1935
Las Palmeras Bailén 2013e	2.43	73	81	1935
Las Palmeras Bailén 2013f	2.61	79	81	1935
Las Palmeras de Colombres	4.85	142	135	1880
Linarejos Linares 1932a	0.50	19	14	1920
Linarejos Linares 1932b	0.33	14	14	1920
Linarejos Linares 1932c	0.41	17	14	1920
Linarejos Linares 2013e	2.04	63	98	1920
Linarejos Linares 2013f	2.58	78	98	1920
Linarejos Linares 2013g	2.60	78	98	1920
Linarejos Linares 2013a	2.80	84	98	1920
Linarejos Linares 2013b	2.83	85	98	1920
Linarejos Linares 2013c	2.92	87	98	1920
Linarejos Linares 2013d	3.26	97	98	1920
Olbius Richier Hyeres P seneg 1912	1.16	38	40	1877
Olbius Richier Hyeres P seneg 2011a	4.68	137	139	1877
Olbius Richier Hyeres P seneg 2011b	5.30	154	139	1877
Orotava palmera de la conquista 1900	7.80	225	220	1685
Parc Vigier Nice_a	5.14	150	149	1865
Parc Vigier Nice_b	5.3	154	149	1865
Parque Caldas de Reis 2013a	2.86	86	98	1920
Parque Caldas de Reis 2013b	3.00	90	98	1920
Parque Caldas de Reis 2013c	3.87	114	98	1920
Plaza de Mayo Buenos Aires	5.06	148	125	1900
Plaza de Pessoa 2015 Las Palmas	6.00	174	170	1850
Quinta Buenavista Colombres	4.75	139	124	1890
Quinta Guadalupe Colombres	3.16	94	105	1916
Villa Hilda Cadavedo	3.11	93	98	1917
Villa Radis Somao Pravia 2012a	3	90	112	1905
Villa Teresa Berbes 2016a	3.4	101	105	1916
Villa Teresa Berbes 2016b	3.63	107	105	1916

with mean 0 and standard deviation 1.

To establish the probability density function for the estimated age as a function of a given value of the stipe/crown coefficient, iterative modeling is done using Markov Chain Monte Carlo simulation (MCMC) in both Stan Bayesian and Zellner-based methods. We provide the ensemble of methods proposed here as *AgePalm* an open-source software, with R scripts, and GitHub repository.

3. Results

3.1. Coefficient stipe / crown and age

The linear regression and parameters values obtained following each one of the three methodologies are similar (Table 2, Fig. 2) and imply that the age of a Canary Island palm is related to the value of the stipe length (S) / crown height (C) ratio according to the function:

Age in years = 28.30 × (S/C ratio) + 7.03 ± σ.

The sources of uncertainty come mainly from errors in the measurement of S and C values (Table 3), however other factors would be involved such as differences in sex of the palm or soil fertility or water availability. The posterior probability distribution function (pdf) of the age value obtained with the methods of Zellner [48] and Stan [33] allows us to have an idea of the most probable age, but also of other possible values, although less probable, which is why they are represented for all the images in Figs. 3 to 5.

The age estimation of palms less than ten years old (not yet adult) appears overestimated in this model, so that in the case of Verschaffelt's and Haage's nurseries plants (Fig. 4) with ages around four years, the estimate age obtained is six to seven years higher than the real one (Table 4, Fig. 4).

Table 2
Main parameters for the regression stipe / crown in *Phoenix canariensis*.

Parameters	Standard linear regression with R least squares estimate	Linear regression with Hamiltonian Bayesian estimate of posterior distribution using RStan	Linear regression with Bayesian modified Zellner estimate of posterior distribution
β_1 (mean intercept)	-0.248418	-0.250268	-0.248423
β_2 (mean slope)	0.035331	0.035341	0.035331
Residual standard error	0.1428 on 67 degrees of freedom	-	-
σ (mean error)	-	0.422332	0.412453

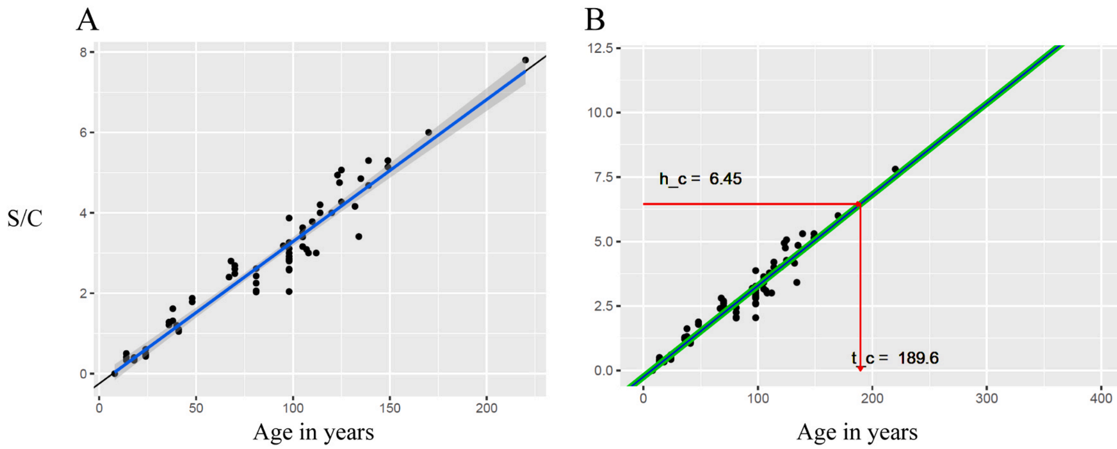

Fig. 2. Linear regression between dimensions and age in *Phoenix canariensis*. A, line resulting from the least square method estimate. B, Zellner's Bayesian method posterior estimate and an example of age estimate (t_c) based on a determined stem /crown ratio (h_c) value of 6.45.

Table 3
Phoenix canariensis variability in the estimation of the coefficient due to measurement imprecision.

	Plaza de Mayo, Buenos Aires			Beverly Hills, Los Angeles		
Parameters	Crown image mm	Stem image mm	Coefficient	Crown image mm	Stem image mm	Coefficient
μ	35.65	158.8	4.95	22.77	180	4.75
σ^2	5.42	32.03	0.08	3.10	5.90	0.13
Max	40	170	5.52	25	185	5.32
Min	31	145	4.34	19	176	4.21

4. Discussion

4.1. Bases, pitfalls and novelty of the proposed methodology

We start from the observed fact that palm leaves reach their maximum size of c. 5.5 m on average, as well as the diameter of the stipe (1 m on average), in the first ten years of their development, especially under normal growing conditions for *Phoenix canariensis*. Thus, the stipe increases in height over the years but not in width [40] and the height of the crown remains almost constant [40]. Considering the above, the ratio between the length of the stipe and the height of the crown of leaves is proportional to the age of the plant.

This method is based on the allometric relationship between the length of the trunk and the crown radius measured along the prolongation of the trunk axis, so it is possible to work with images as long as they are clear and undistorted. The novelty of the method is that no field measurement of the parameters in meters is necessary and this greatly simplifies the task, including no need for metric or graphic scales.

The stem-root transition can be obscured by changes in ground level, increase or decrease, due to erosion or the input of materials. In the field it is important to locate the point where the roots begin. We must consider that in the case of centenary specimens, determining the base of the trunk can be very difficult, due to filling works as it happens with the centenary palm trees of Elche Municipal Park (Spain), where cultivation terraces were filled several meters to level the spaces and that carries that to an inferior estimate of the age of the palm trees located on the lower terraces, near the Vinalopó river.

We have addressed the problem that older specimens tend to grow more slowly, which seems obvious, but also, as can be seen in Fig. 2, specimens over 200 years old show an index value almost on the adjustment line. In our opinion, this is due to the fact that in parallel there is a slight and progressive decrease in the crown radius, which keeps the allometric relationship within the mean values.

The part of the variation of the dependent variable unexplained by variation in the independent variable is assumed to be produced by an unobserved random "error" or "disturbance" variable (cf. [48]). Although Zellner [48] assumed the absence of measurement errors, to assess the relevance of possible measurement errors of stem length and crown length on S/C ratio values, we gave fifteen subjects the same two images of Canary Island palm trees, one of those growing in Plaza de Mayo in Buenos Aires (Argentine Republic) and another in Beverly Hill in Los Angeles (USA). The variability of Stipe/Crown coefficients as a result of the incertitude of the measurements is summarized in Table 3.

Concerning the impact of different stress factors, we have found similar phenomena in palm trees of *Phoenix dactylifera* L., growing under strong aridity and salinity stress for decades at Guardamar del Segura sand dunes (Alicante, Spain) and with well-known date of plantation. There the palm trees are smaller in relation with those of similar age in the palm groves of the nearby but they also present smaller crown radiuses, giving a similar allometric relationship.

This procedure will allow visual age estimation for adult individuals of numerous Arecaceae such as species of the genera *Phoenix, Trachycarpus* or *Washingtonia*. This is done in terms of a probability distribution for age, which depends on the comparison samples available through linear regression, and can be updated as individuals of known age become available by other means: historical records, historical image series or radiocarbon dating where applicable.

Furthermore, provided the availability of a wide sample of oil palm individuals with different known ages usually determined from documents of the plantation, dated photographs, etc., a linear regression model could similarly be produced for oil palm (*Elaeis guineensis* Jacq.) and other palm tree species of economic value.

4.2. Early events of diffusion for Phoenix canariensis as ornamental plant and the age estimate of singular palm trees

The earliest documented introduction of the Canary Island date palm into mainland European gardens was by Norwegian botanist Christen Smith. During a stay in Tenerife in 1815, in the autumn, Smith collected *P. canariensis* seeds for the botanical garden in Oslo. At least one *P. canariensis* palm grew from those seeds and survived in the glasshouse in Oslo until 2000 [49]. Although there is no evidence of this, it cannot

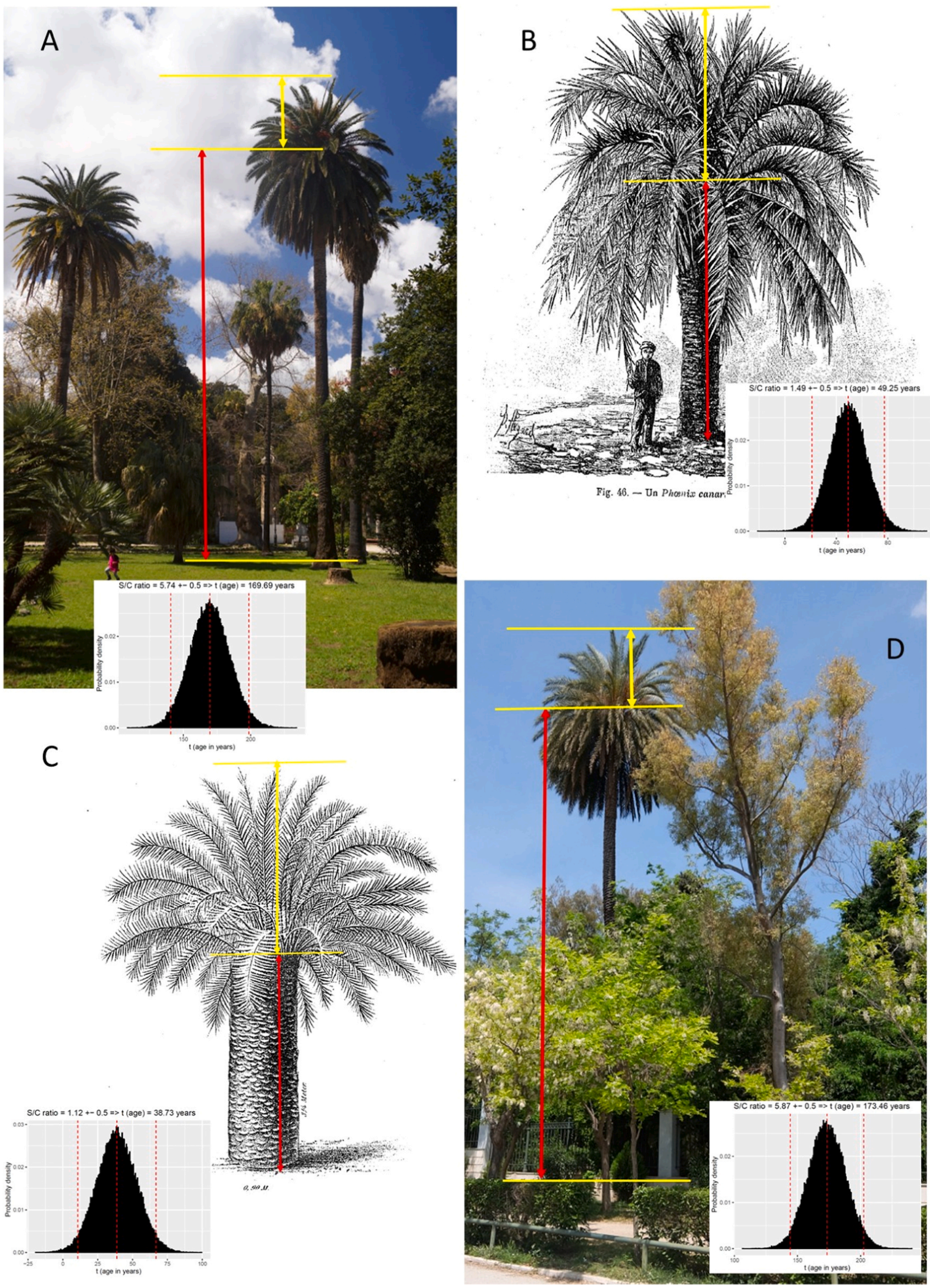

Fig. 3. Evidence for the 1840 – 1845 diffusion event for *Phoenix canariensis.* A, Villa Giulia (Palermo) in 2015, Image: D. Rivera & C. Obón. B, Montevideo Image: André [4]. C, Athens Image: Regel [25]. D, Athens in 2017, Image: D. Rivera & C. Obón. All images are accompanied by the posterior probability distribution function for their estimated ages, using Zellner's Bayesian method and MC.

be ruled out that the activity of collection and study of the Canary flora by Philip Barker-Webb and Sabin Berthelot, which lasted in the field until the 1830s, contributed to a limited diffusion of seeds of what they called *P. dactylifera* var. *jubae* [47].

However, the most relevant episode for the diffusion of *Phoenix canariensis* outside the Canary Islands is linked to the collecting activity of Herman Wildpret since the 1860 s with the consequent sale of seeds to the most important nurseries in Western Europe from where the Canary Island palm was introduced in elegant houses and gardens all over Europe and at the same time in America [18,27,30,36,49].

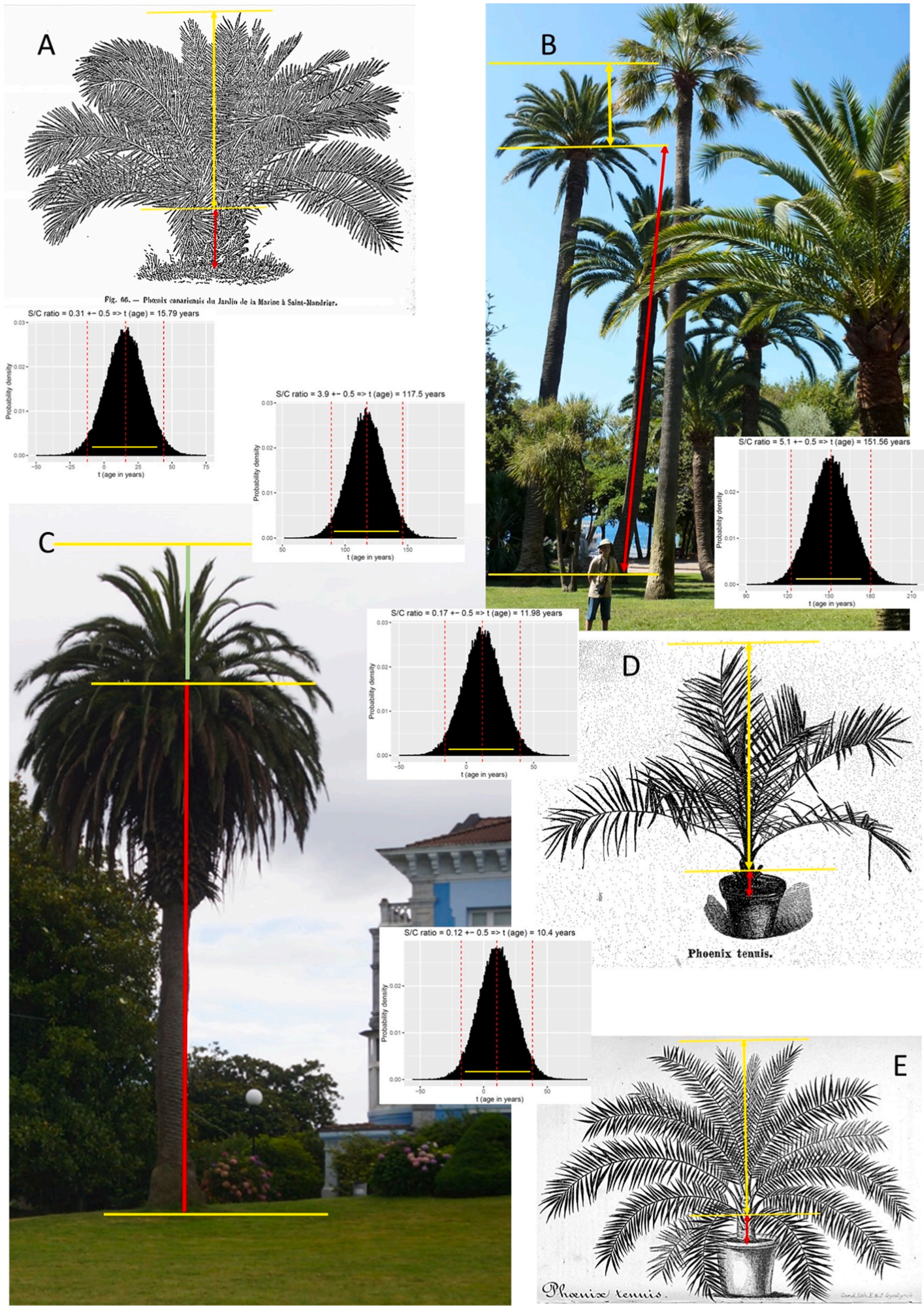

Fig. 4. Evidence for the 1860 – 1870 diffusion event for *Phoenix canariensis*. A, Saint Mandrier (France), Image: Chabaud [11]. B, Parc Vigier, Nice (France) in 2011, Image: D. Rivera & C. Obón. C, Colombres (Spain) in 2013, Image: D. Rivera & C. Obón. D, Haage Nursery at Erfurt (Germany), Image: Neubert [21]. E, Verschaffelt nursery at Gent (Belgium), Image: Verschaffelt [45]. All images are accompanied by the posterior probability distribution function for their estimated ages, using Zellner's Bayesian method and MC.

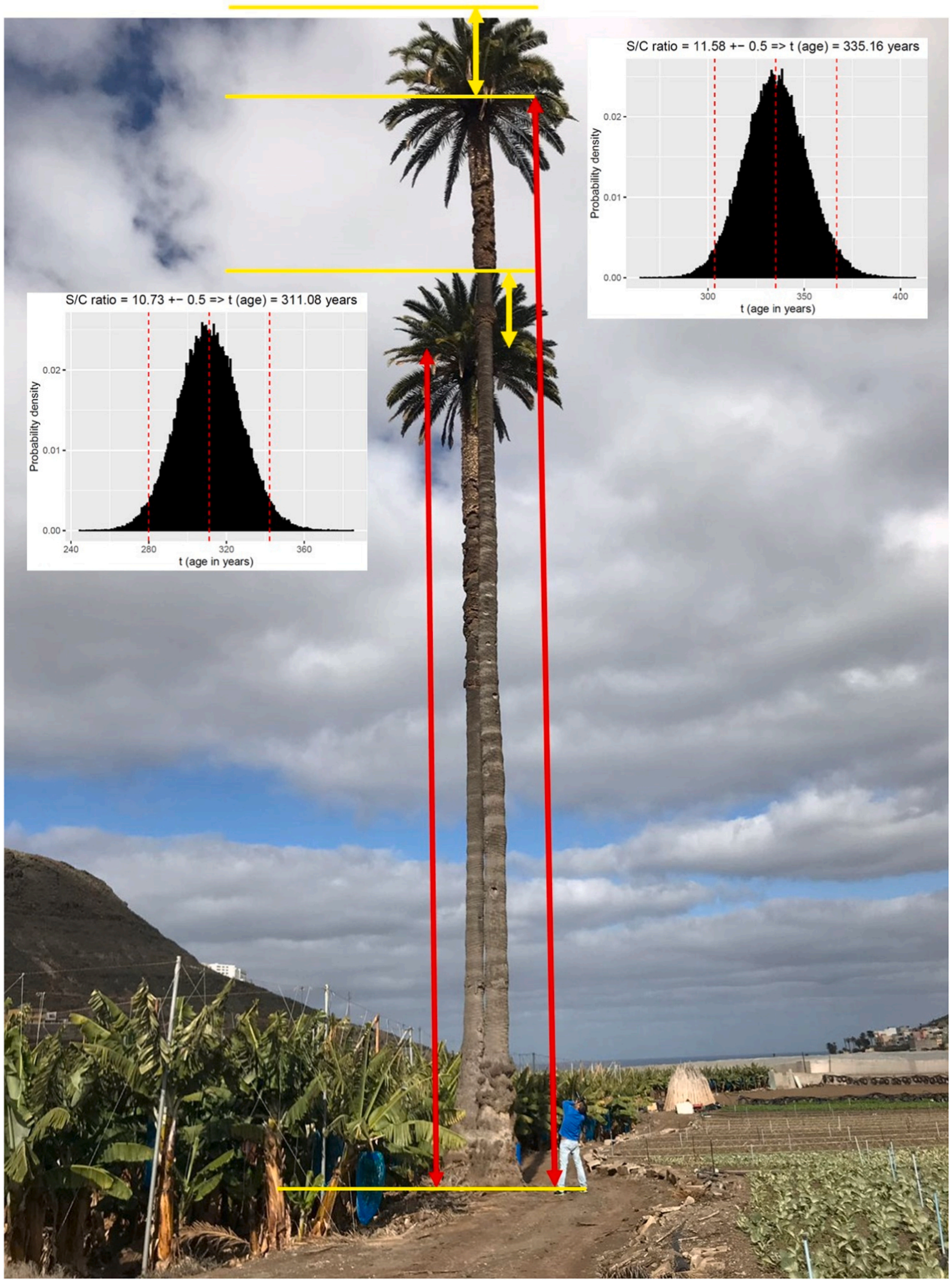

Fig. 5. Evidence for the oldest living palm trees of *Phoenix canariensis*. Tenoya (Gran Canaria, Spain), Image: P. Sosa. All images are accompanied by the posterior probability distribution function for their estimated ages, using Zellner's Bayesian method and MC.

The results of the study of images published throughout the 19th century and of photographs of surviving specimens at the beginning of the 21st century have allowed us to differentiate at least two groups of coetaneous Canary Island palms in the gardens of Europe. The first would have its origin in a seed distribution that would have occurred around 1840 (Table 4 and Fig. 3) and the second would coincide with the distribution made by Wildpret in the early 1860s (Table 4 and Fig. 4). Regarding the first, which would give rise to specimens cultivated in Athens, Palermo, Seville and Montevideo (Fig. 4), it could also be related to the Canary palms existing in Egypt prior to those distributed by Wildpret and mentioned by Chabaud [11]. This first event merits further investigation. Concerning the Athens' specimen which was still alive in 2017 (Fig. 1), it was described by Regel [25] under "*Phoenix cycadifolia*", a name which was first used by Trautvetter [41] in the list of additions to the palm collection of the Imperial Botanic Garden of St. Petersburg during the year 1874 [28].

In the group of Canary Island palms distributed from 1860 onwards, the role of nurserymen such as Verschaffelt [43–45] and Haage as well as those of the Côte d′Azur should be noted (Fig. 2). The palms of Viscount Vigier in Nice (France), mentioned by Chabaud [11] were still alive in 2011 (Fig. 4), but at the time of publication of this paper they have disappeared destroyed by the red palm weevil (*Rhynchophorus ferrugineus* Olivier) which is the main threat for palms since 2000s [10, 14].

4.3. Visual age estimate using linear regression of exceptional *Phoenix canariensis* individuals in the Canary Islands

Related to the development of a more adequate protection and conservation policy for *Phoenix canariensis* "in situ", the estimate of the

Table 4
Phoenix canariensis evidence for two main dissemination events from the Canary Islands abroad during the 19th century.

Locality	S/C	Age estimated in years	Date Image	App. Date Planting
Event c. 1840				
Gardens of the Palace (Athens, Greece)	1.12	38.73	1879	1840–1845
Cardens of the Parliament (Athens, Greece)	5.87	173.17	2017	1840–1845
Villa Giulia (Palermo, Italy)	5.74	169.5	2015	1847–1850
Carmen de los Mártires (Granada, Spain)*	1.41	46.9	1895	1850
Carmen de los Mártires (Granada, Spain)*	1.65	53.7	1895	1845
Parque de Maria Luisa (Seville, Spain)	5.64	166.66	2013	1845–1850
Giardino Botanico (Roma, Italy)	5.7	168.4	2013	1845–1850
Montevideo (Uruguay)	1.49	49.2	1893	1840–1845
Event c. 1860 and later				
Parc Vigier (Nice, France)	5.1	151.4	2011	1865
Saint Mandrier (France)	0.31	15.81	1882	1866
Verschaffelt Nurseries at Gent (Belgium)	0.12	10.4	1869	1862
Haage Nurseries at Erfurt (Germany)	0.17	11.84	1873	1866
Archivo de Indianos (Colombres, Spain)	3.90	117.41	2013	1890–1900
Emilio Luque Square (Córdoba, Spain)**	4.77	141.94	2013	1880–1884

Note: (*) Images in La Ilustración Artística vol. 395 (1895). (**) Image in Lora [17]

age of palm specimens notable by their dimensions can help to define priority localities and communities for conservation [22,35]. In this sense, we have calculated the ages of unique specimens (Table 5), among which the two individuals from Tenoya (Gran Canaria) stand out (Fig. 5), for which the estimated age is over 300 years and in one of the two closes to 350 years.

We have addressed the case of the "Palm Tree of Conquest". An extraordinary storm killed this palm tree in 1919. The canaries attributed to this male specimen an extraordinary age of four centuries [9]. However, our analysis of the available image only allows the estimate of 221 years.

5. Conclusions

The proposed methodology is promising both in the field of horticulture and in the conservation of biodiversity. We provide an open-source software, with R scripts, and GitHub repository. Although it is very sensitive to the quality of the measurement of the length of the trunk and the radius of the crown, it provides an estimate on a probabilistic basis that is appreciably approximate. It would be convenient to calibrate it using other dating techniques, including radiometric ones and to approach the analysis of the influence of the plant sex (male or female) in the estimated age. We are working on extending its application to the date palm (*Phoenix dactylifera*).

This work presents implications for forestry but also for urban gardens and parks management and policy. In the current context in which the red palm weevil plague is extensively destroying or threatening historical plantations and alignments of Canary Island palm trees, as emblematic as those of the Promenade des Anglais in Nice (France) or Beverly Hills in Los Angeles (USA), where it is interspersed with *Washingtonia*, it is important to have a tool that allows us to intensify the activity of protection and treatment of unique specimens due to their historical and cultural value linked to their age, among other aspects.

Table 5
Phoenix canariensis estimated age for oldest specimens in the Canary Islands (Spain).

Locality	S/C	Age estimated in years	Date Image	App. Date Germination
Tenoya (Gran Canaria, Spain)	11.58	334.93	2017	1682
Tenoya (Gran Canaria, Spain)	10.73	311.95	2017	1706
Telde (Gran Canaria, Spain)	11.18	323.26	2017	1694
Parque San Telmo (Gran Canaria, Spain)	7.48	218.6	2019	1801
Parque San Telmo (Gran Canaria, Spain)	5.26	155.8	2019	1863
Las Palmas (Gran Canaria, Spain)	4.04	121.9	2019	1897
La Oliva (Fuerteventura, Spain)	4.62	137.7	2017	1879
La Laguna (Tenerife, Spain)	4.89	145.34	2013	1868
Benchijigua (La Gomera, Spain)	6.69	186.4	2013	1827
Alojera (La Gomera, Spain)	5.10	151.4	2016	1865

CRediT authorship contribution statement

Diego Rivera, Javier Abellán, José Antonio Palazón: Conceptualization, Methodology, Software, Writing- Original draft preparation. **Concepción Obón, Manuel Martínez-Rico:** Data curation. **Javier Valera, Pedro Sosa, Francisco Alcaraz:** Visualization, Investigation. **Pedro Sosa, Concepción Obón:** Supervision and Project administration. **Diego José Rivera:** Software, Validation. **Dennis Johnson:** Reviewing and Editing,

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Core data are furnished in the paper the R scrip will be available at Phoenix-Spain.org.

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