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Growth in Thickness of Monumental English Oaks *Quercus Oobur*, and Their Age, Health Status and Dust Fall in Bayesian Approach

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Abstract

This paper presents an ecological analysis of the growth in thickness of monumental English oaks in relation to the age of trees, their health status, and dust fall in the immediate environment. The Bayesian modeling of empirical data was proposed via the MCMC technique - known as Gibbs sampling in the BUGS software. The usefulness of the methodology, was accentuated in such ecological assessments.

Keywords: growth in thickness, age, health status, dust fall, BUGS

Introduction

Magnificent trees have been a human interest for a long time and in different countries they are embraced by protective laws. One of the forms of protection of such objects in Poland is their establishment as natural monuments. This fact has considerable importance in Poland because it is one of the unique countries in Europe where a relatively large number of such monuments have been preserved [1]. Among these trees, English oaks (rarely sessile oaks), small-leaf limes (rarely broad-leaf limes) as well as European beeches are the prevailing species [2, 3, 4, 5], while conifers are only 10% of the preserved monuments [4].

Each tree during its lifetime is under an influence of several factors that cause fluctuations in its growth in thickness. The factors that affect the trees permanently are climate, biotope conditions, and air pollution. This is why data concerning the annual growth levels of a certain object comprise the information of its environment as well as of the tree itself. It is noted in literature that the level and the tempo of decrease in thickness are measures of the tree stand deterioration and some of the most important signs suggesting the tree's future development [6, 4, 7, 8]. The trees react to disadvantageous biotope conditions first in reduction of annual thickness growth, and next (in subsequent 4 to 8 years) in exterior changes such as yellowing of leaves (chlorosis) and drying of the top part of the corona [8].

Apart from the factors mentioned, undoubtedly the age of trees determines the intensity of growth and their liability to different environmental factors. Generally, the growth in thickness of trees is the most intensive in the first period of life, after that the intensity of this process decreases [9].

The health status of monumental trees in Poland is apprehensive, however [4, 1, 10]. [11] suggests that the observed destructive processes in the environment cause paucity of the tree stands, eliminating particularly old objects. It is assumed that in the group of human factors, the most important reason for the deteriorating health status of trees is air pollution. Related to this is the dust fall problem.

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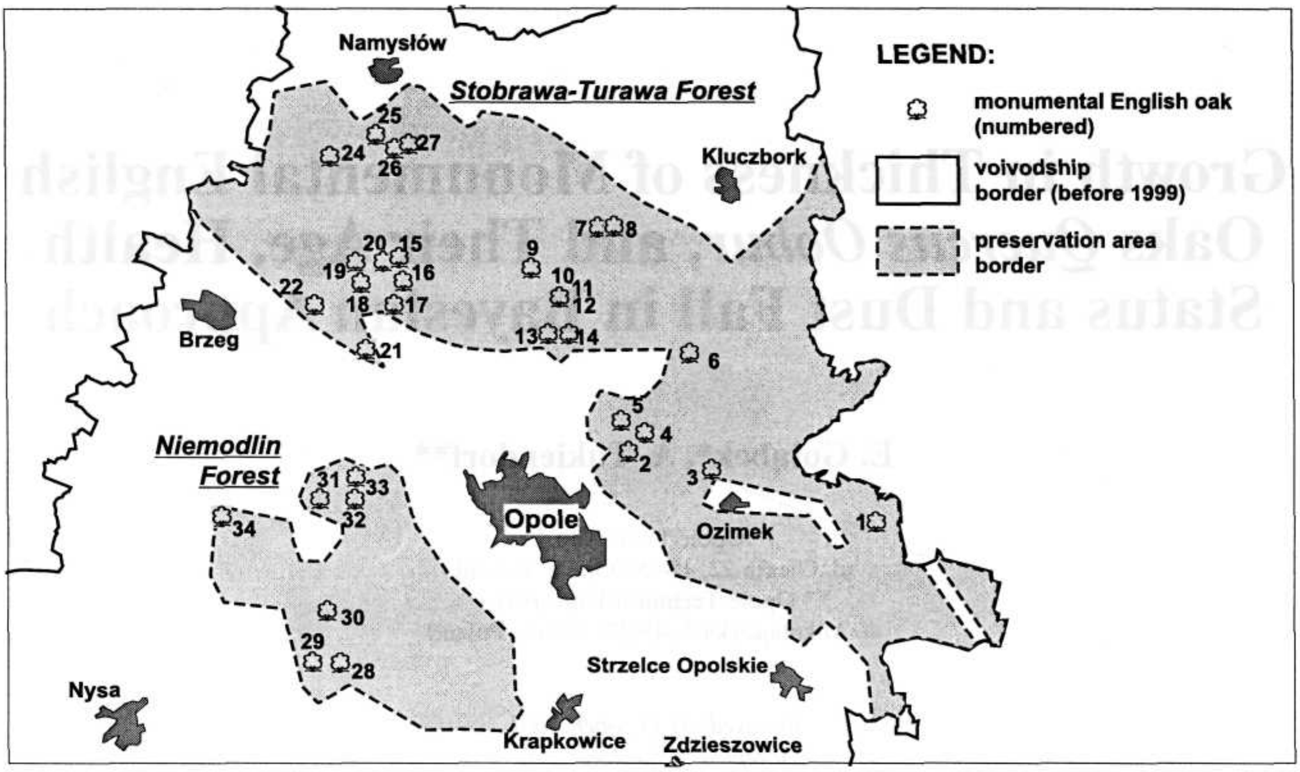

Fig. 1. Preservation areas and locations of analyzed monumental English oaks *Quercus robur.*

Dusts emerge in the environment as a consequence of organic and inorganic weathering of Earth's shell as well as a result of anthropogenic processes. Among the latter source, the four main groups of dust origins can be distinguished:

- furnace devices, the substances contain coal, soot, metal oxides, silicates, and more;
- construction material industry emitting dusts con taining calcium oxides, as well as silicon and aluminum oxides, silicates, carbonates, and more;
- iron works and foundries releasing manganese, fer rous, titanium, zinc, vanadium oxides, phosphates, fluorites, and more;
- non-ferrous foundries that are a source of silicon and aluminum oxides and heavy metals such as lead, zinc, cuprum, cadmium, and more[12, 13].

In 1994 in Poland the overall emission of dust reached 1.395 thousand tons, most of which (46.3%) derived from power industry and industrial technology. In comparison with 1990 (1.950 thousand tons) the amount systematically decreased. Among the voivodships the biggest volume of dust (82.5 thousand tons) was emitted from Katowice, whilst Opole voivodship was ranked on the seventh place (19.0 thousand tons) [14].

Depending on the branch of industry from which it is derived, dust differs in toxic properties to plants. However, despite several studies considering this problem, a lot of questions remain unscrutinized.

It is well known that dust covers leaf blades with a layer of various thicknesses which deteriorate the resistance of epiderm cells and choke cuticles, limiting, in turn, gas exchange and transpiration, and disturbing life processes. The deposited dust, due to its physical-chemical properties and thickness of layer, can also change the absorbed/reflected light ratio perturbing metabolic conversion. Furthermore, scientific literature discusses the temperature increase in leaves covered by dust. However, the majority of scientists suppose that the largest damages result from chemical reactions of certain dust components solved in water occurring on the leaf surface. Such solutions can act mordantly to leaf blades (e.g. solutions with cement dusts), or can infiltrate them, causing chemical conversions. The degree of such damages depends on the chemical composition of dusts, their impact duration and concentrations of the produced solutions. Nevertheless, the impact of dusts on plants is importantly less hazardous than of toxic gases [12, 13]. Generally, the most sensitive to dustiness are conifers and those species of deciduous trees that have leaves and shoots covered by hairs and cutin [15].

The aim of this study was to assess the possible influence of dust on the growth in thickness of English oaks - monumental trees, using modern statistical methodology. In the ecological analysis the age of trees and their health status were taken into account as well. The statistical modeling was performed in the BUGS software adopting Markov chain Monte Carlo (MCMC) technique known as Gibbs sampling. The paper pays more attention to flexible and extensive analytical opportunities provided by the applied methods rather than explicit biological aspects of the question under study.

Materials and Methods

The research was conducted in the years 1995-96 and the two largest preservation areas in the Opole voivodship were the fields of this study:

- Stobrawa-Turawa Forest (with preservation surface of 179,305 ha), and

- Niemodlin Forest (with preservation surface of 48,189 ha).

Both forests cover 82.4% of surface of overall landscape preserves in the region. The focus on these territories was due to the fact that they are especially valuable from the natural and scientific point of view.

In the forests mentioned, 36 existing English oaks

Table 1. List of analyzed monumental English oaks *Quercus robur* (according to the state of 31.12.1995).

No. of oak	Registration no.	Preservation area	Borough	Municipality	Major forest division	District	Forest division	Forest department
1	406	Stobrawa-Turawa	Kolonowskie	Kolonowskie	Zawadzkie	Kolonowskie	Kolejka	111 d
2	13	Stobrawa-Turawa	Turawa	Turawa	non-appliable	non-appliable	non-appliable	non-appliable
3	162	Stobrawa-Turawa	Turawa	Turawa	non-appliable	non-appliable	non-appliable	non-appliable
4	325	Stobrawa-Turawa	Turawa	Turawa	non-appliable	non-appliable	non-appliable	non-appliable
5	293	Stobrawa-Turawa	Turawa	Turawa	Turawa	Turawa	Osowiec	136 c
6	321	Stobrawa-Turawa	Turawa	Bierdzany	non-appliable	non-appliable	non-appliable	non-appliable
7	31	Stobrawa-Turawa	Murów	Radomierowice	non-appliable	non-appliable	non-appliable	non-appliable
8	320	Stobrawa-Turawa	Murów	Radomierowice	non-appliable	non-appliable	non-appliable	non-appliable
9	39	Stobrawa-Turawa	Murów	Okoły	Kup	Pokój	Czarna Woda	191 d
10	40	Stobrawa-Turawa	Murów	Zagwiździe	Kup	Kup	Murów	5 d
11	266	Stobrawa-Turawa	Murów	Zagwiździe	Kup	Kup	Murów	5 f
12	263	Stobrawa-Turawa	Murów	Zagwiździe	Kup	Kup	Murów	6 b
13	332 a	Stobrawa-Turawa	Murów	Grabczok	Kup	Kup	Brynica	82 c
14	43	Stobrawa-Turawa	Murów	Grabczok	Kup	Kup	Brynica	86 f
15	411	Stobrawa-Turawa	Popielów	Kuźnica Katowska	Brzeg	Karłowice	Roszkowice	54 b
16	412	Stobrawa-Turawa	Popielów	Kuźnica Katowska	Brzeg	Karłowice	Roszkowice	64 a
17	35	Stobrawa-Turawa	Popielów	Popielów	Kup	Popielów	Popielów	43 c
18	438	Stobrawa-Turawa	Popielów	Kurznie	non-appliable	non-appliable	non-appliable	non-appliable
19	439	Stobrawa-Turawa	Popielów	Kurznie	non-appliable	non-appliable	non-appliable	non-appliable
20	410	Stobrawa-Turawa	Popielów	Kurznie	Brzeg	Karłowice	Roszkowice	33 b
21	352	Stobrawa-Turawa	Popielów	Rybna	non-appliable	non-appliable	non-appliable	non-appliable
22	414	Stobrawa-Turawa	Popielów	Stobrawa	Brzeg	Karłowice	Rybno	245 c
23	81	Stobrawa-Turawa	Namysłów	Minkowskie	Namysłów	Namysłów	Świty	204 b
24	313	Stobrawa-Turawa	Namysłów	Minkowskie	Namysłów	Namysłów	Świty	206 j
25	86	Stobrawa-Turawa	Namysłów	Nowe Smarchowice	Namysłów	Namysłów	Ziemiełowice	144 f
26	83	Stobrawa-Turawa	Namysłów	Nowy Folwark	Namysłów	Namysłów	Ziemiełowice	152 b
27	102	Stobrawa-Turawa	Namysłów	Jastrzębie	non-appliable	non-appliable	non-appliable	non-appliable
28	4	Niemodlin	Korfantów	Kuźnia Ligocka	Tułowice	Tułowice	Kuźnia Ligocka	225 a
29	422	Niemodlin	Łambinowice	Wierzbie	Tułowice	Tułowice	Kuźnia Ligocka	222 h
30	241	Niemodlin	Tułowice	Ligota Tułowicka	Tułowice	Tułowice	Tułowice	24 f
31	21	Niemodlin	Niemodlin	Szydłowiec Śl.	non-appliable	non-appliable	non-appliable	non-appliable
32	279	Niemodlin	Niemodlin	Rzędziwojowice	Opole	Dąbrowa Op.	Sosnówka	166 Aa
33	276	Niemodlin	Niemodlin	Rzędziwojowice	Opole	Dąbrowa Op.	Sosnówka	166 f
34	100	Niemodlin	Grodków	Kopice	Tułowice	Niemodlin	Dębina	64 Ai

Quercus robur that are singular natural monuments figuring in the Voivodship Nature Conservation List were scrutinized. Two trees were excluded from analysis because of the putridity of their wood. The information of the monumental trees with their geographical locations in preservation areas was set in Table 1 and Figure 1.

Wood Bore Sampling

The wood bore sampling was conducted for NESW directions using a 40 cm Pressler's drill. The analyzed trees were bored on the 130 cm height and after this operation the gaps after boring were protected against infection [16, 17].

Table 2. Biological and environmental data for studied English oaks.

No. of oak	Average annual growth (1976-1985) [mm]	Average annual growth (1986-1995) [mm]	Age (1995) [year]	Health status (1995)	Average dust fall (1986-1995) [g/(m^2 × month)]
1	3.5	3.2	138	2	3.32
2	3.3	3.0	186	2	2.81
3	2.4	2.8	264	2	3.02
4	3.6	3.8	178	2	2.72
5	1.6	1.5	454	2	2.73
6	2.6	2.6	236	2	2.80
7	3.1	2.6	160	3	2.80
8	3.0	3.0	200	2	2.81
9	1.9	1.8	273	2	2.20
10	1.2	0.7	440	5	2.36
11	2.7	2.9	302	2	2.36
12	1.8	2.1	387	2	2.35
13	1.5	1.8	279	4	2.60
14	1.6	1.6	404	3	2.65
15	1.0	0.8	592	4	3.80
16	1.4	1.2	592	3	3.68
17	1.6	1.2	370	4	3.47
18	2.8	3.2	156	2	4.40
19	2.3	2.0	148	2	4.39
20	1.6	1.3	216	2	4.16
21	2.8	2.5	160	2	3.67
22	2.0	2.7	277	3	4.33
23	2.4	2.5	351	2	3.60
24	1.8	2.0	240	2	3.53
25	2.2	2.0	383	2	3.59
26	2.2	2.1	258	2	3.53
27	1.8	1.2	298	4	3.20
28	1.8	2.3	329	2	4.55
29	1.3	0.8	376	5	4.56
30	1.4	1.4	235	2	3.42
31	2.2	2.2	559	3	3.02
32	1.9	1.9	462	2	2.79
33	0.8	0.6	590	5	2.75
34	2.2	2.3	326	2	3.59

Annual Growth

The growth in thickness of the analyzed trees was measured based on the wood bore samples for the 1976-85 and 1986-95 periods. From these results the average annual growth in thickness was estimated for each tree in the decades [16, 17].

Age

The ages of the monumental trees were estimated according to Pacyniak's method [16, 17]. In this technique, for the analyzed height of the trees, the age was calculated based on the average of annual growth in thickness. Using this method the estimation of a tree's age is biased by an error of approximately 20 years [16, 17].

Health Status

Evaluations of the health status of monumental oaks was based on a five-degree gradation scale given by [10], in which each of the degree determines the following health condition of trees:

1) trees completely healthy with no loss and absence of pests;
2) trees with partially mortifying thin branches in top parts of the crown with a presence of plant and animal pests;
3) trees with 50% dead crown and log attacked by pests;
4) trees with 70% dead crown and log and large losses in wood;
5) trees with over 70% dead crown and log with many tree hollows.

Dust Fall

The levels of the average dust fall at locations of the analyzed monumental English oaks were calculated based on air monitoring provided by the Research Forest Institute [18]. The analysis comprised the information concerning the dust fall in Opole voivodship that was measured via the sedimentation method and expressed in grams for a square meter for a month ([g/(m^2 x month)]).

Statistical Approach

In statistical reasoning, the results of natural research - generally stated as numerical data quantifying and qualifying the analyzed phenomena - are a consequence of the rules of many combined statistical processes. They, in turn, consist of different types of simple and complex mathematical models and determine the nature of the analyzed phenomena. In each type of mathematical modeling (deterministic and stochastic), two basic matters are considered: theoretical (i.e. an original), and practical (i.e. a model), whilst the modeling process itself in a general approach is an approximated "reproduction" of the fundamental, the most characteristic properties of the original (the model reflects some similarity attributes of the original) [19].

Such analyzed (consistently with modern statistical trends) phenomena result in creation of many universal computational methods. In recent years, to revolutionary achievements in ecology, the application of Bayesian methods together with Markov chain Monte Carlo (MCMC) techniques are of special note (see: e.g. [20]). The basic philosophy behind MCMC is to take a Bayesian approach and carry out the necessary integrations using Markov chain and simulation known as Monte Carlo. The simulation is conducted via sophisticated mathematical algorithms, among which the most popular are Metropolis-Hastings and Gibbs (the first is a general form of the second) [20]. In this method, a Bayesian or full probability model is assumed in which all quantities are treated as random variables and a joint distribution over all unobserved (parameters and missing data) and observed quantities (the data) is defined. A conditioning on the data in order to obtain a posterior and a marginal distribution over the parameters allows computation of estimates of their expected values. However, instead of calculating exact or approximate estimates, this computer-intensive technique generates a stream of simulated values depending on the number of iteration steps. To perform MCMC additional tools are required to form samples from the relevant distributions, monitor the stream for convergence, and summarize the accumulated samples (see: e.g. [20] for details).

Based on this methodology, a number of computer programs have been created, among which BUGS ("Bayesian Inference Using Gibbs Sampling") - a non-commercial software of the Medical Research Council - Biostatistics Unit in Cambridge, UK - is one of the leading and most popular MCMC Bayesian statistical tools [21].

In the statistical modeling of the studied problem it is assumed that the growth in thickness of English oaks in 1976-85 and 1986-95 is reciprocal to their age and proportional to their health status and dust fall at locations of the trees. In research the assumed probabilistic model for 34 oaks and 2 decades was expressed by the following description (a general form):

$$\text{for } i = 1, \ldots, 34 \text{ (oaks) and } j = 1, 2 \text{ (decades)}$$
$$\text{growth.in.thickness}_{ij} \sim N(\mu_{ij}, \sigma)$$
$$\mu_{ij} = \beta_0 + \beta_1 \times \text{age}_{ij}^{-1} + \beta_2 \times \text{health.status}_i + \beta_3 \times \text{dust.fall}_{ij}$$

The estimation of dust fall levels in the 1986-95 decade for the locations of oaks was performed via a standard kriging method [22] from the form-fitted interpolations grids.

Dendrologic Measurements and Results of Statistical Computation

The average growths in thickness of monumental oaks in the examined decades, with the age of trees, their health status and additional estimates of dust fall in the analyzed locations are set in Table 2.

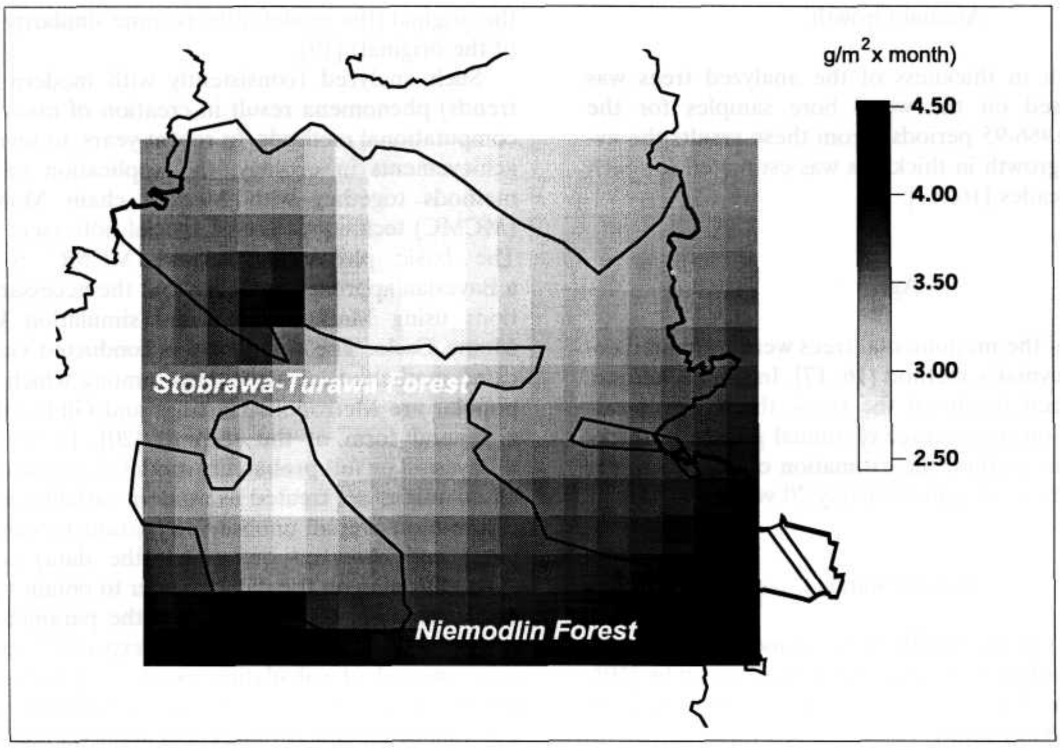

Fig. 2. Spatial distribution of average dust fall in 1986-95.

Additionally, a spatial distribution of average dust fall in the research area in 1986-95 is presented in Fig. 2.

The results of the posterior Bayesian analysis for the assumed statistical model are set in Table 3 (in the study, the computation based on a burn-in of 1,000 iterations and following 50,000 production-run samples provided convincing evidence of converged distributions of the streams of values during the Gibbs sampling).

Table 3. Posterior analysis of a model's parameters.

Parameter	Mean	Standard deviation	Credible 95% intervals
β_0	2.524	0.4113	(1.709; 3.329)
β_1	234.8	39.85	(157.3; 313.6)
β_2	–0.3163	0.06375	(–0.4427; –0.1909)
β_3	–0.1559	0.1014	(–0.3506; 0.04608)

Based on the obtained standard deviations of simulated values, the stability of means for a particular model's parameters can be asserted. This fact validates the statistical significance of the estimated parameters and the accuracy of the assumed statistical model. An example of the trajectory of the simulated values for the dust fall regression slope parameter (p_3) is presented in Figure 3.

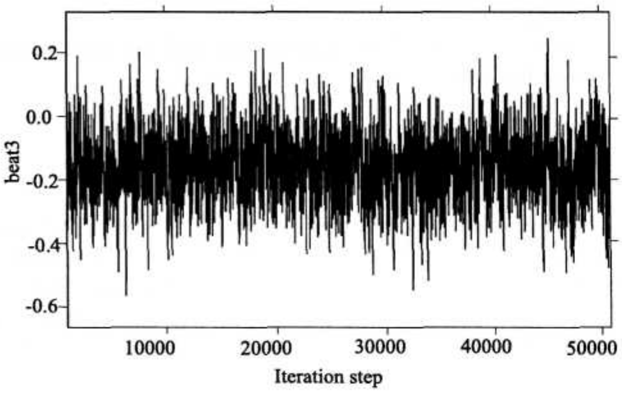

Fig. 3. Trajectory of simulated values of β_3 parameter versus iteration steps.

Conclusions

The above results that were obtained using the measurement (empirical) data and the assumed statistical model allow us to define the e growth in thickness of the analyzed English oaks as a function of the age of trees, their health status, and the dust fall quantity as follows:

growth.in.thickness (average in decade) [mm] =
2.5 (constant) [mm] +
+ 235 / age [year] - 0.32 x health.status [degree] + -
0.16 x dust.fall (average in decade) [g/(m^2 x month)].

Substituting the appropriate values in the given formula, the expected growth in thickness of the trees can be estimated by multiplying the quantities of interest with the computed model's parameters.

Moreover, from the relation given above, despite the apparent influence of the oaks' age and health status on the growth in thickness, the negative effect of the dust fall on the trees' development is clearly indicated. This fact may lead to a certain speculation over the etiology of the growth deterioration in the studied monumental oaks and the visible contribution of environmental pollution. Certainly, at this stage of research the ecological problem can be signaled only and no definite conclusion can be reached. Some more extended scientific investigations, such as case-control or longitudinal studies, as well as a further spatial analysis shall lead to less speculative divagations if carried out in the future. The authors also realize that including more dendrological aspects may be advantageous for the research outcomes. Notwithstanding the confinement of the problems considered in this study, the proposed Bayesian methodological approach, in the authors' opinion, is perfectly suitable, like no other, for such an ecological inference, giving the opportunity for a credible scientific assessment.

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