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ASSESSMENT OF INFLUENCE OF AGE OF TREES AND DUST FALL ON DEFOLIATION OF THE SCOTCH PINE IN THE REGION OF OPOLE AND SOME NEIGHBORING TERRITORIES USING BAYESIAN APPROACH

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ABSTRACT

The paper presents an ecological analysis of the defoliation of Scotch pines in relation to the age of trees, and the dust fall in the immediate environment. The Bayesian modeling of empirical data was proposed here via MCMC technique – known as Gibbs sampling in the BUGS software. The usefulness of the methodology was accentuated in such ecological assessments.

Key words: Scotch pine, defoliation, age, dust fall, BUGS

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INTRODUCTION

The health status of forests is a function of a variety of biotic, abiotic and anthropogenic factors. The reduction of assimilation surface of trees and resulting defoliation of leaves or needles in a certain biotope and a climate is an exact measure of the health condition (Łonkiewicz *et al*. 1997).

The defoliation is mainly related to a natural process that is aging, as well as to some morbidities and a certain environmental pollution (the latter may cause health deterioration of trees). Since a more intensive defoliation process in older trees is an apparent biological phenomenon during their life development, the influence of some environmental factors on different tree species has not been scrutinized enough so far, either it is still disputable. Hence, explaining some crucial biological-environmental relations not only may have cognitive values but also can be used in health preventive measures of forests' saving plans having an economic justification.

The damages of forests in Poland have been monitored annually since 1989 as a part of the State Environmental Monitoring based on the Permanent Observational Areas (POAs) that are localized in the pine, spruce, fir, oak, beech, and birch forest stands in the country. A placement and a choice of POAs reflect the surface, age, species and health status structures of trees (Łonkiewicz *et al*. 1997). Based on the losses of cuticles in leaves/needles, an evaluation of damages of trees is performed (Wawrzoniak *et al*. 1996).

A Scotch pine *Pinus silvestris* L. is the most common species of trees in Poland. Its forest stand covers 69.3 % of the total tree surface in the country (Sobczak 1996). Moreover, it is included in the species of the great sensitivity to pollution (Kluczyński 1976, Greszta 1987, Białobok *et al*. 1993, Jaworski 1994). Jaworski (1994) claims that especially sulfur dioxide, hydrogen fluoride and nitro compounds may be very hazardous for the tree development. Whereas Kluczyński (1976) includes the Scotch pine in the species of a middle resistance to fluoride compounds. However, one of the most important and unquestionable factors influencing the health status of the Scotch pine is dust (e.g. Białobok 1989, Greszta 1987).

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 anthropogenic source, the four main groups of dust origins can be distinguished:

- furnace devices; the substances contain coal, soot, metal oxides, silicates and others;
- construction material industry emitting dusts containing calcium oxides as well as silicon and aluminum oxides, silicates, carbonates and others;
- iron works and foundries releasing manganese, ferrous, titanium, zinc, vanadium oxides, phosphates, fluorites and others;
- non-ferrous foundries that are a source of silicon and aluminum oxides and heavy metals such as lead, zinc, cuprum, cadmium and others (Białobok 1989, Greszta 1987).

Following the information from the General Statistical Office, in 1994 in Poland the overall emission of dust reached 1,395 thou. tons, most of which (46.3 %) derived from power industry and industrial technology. In comparison with 1990 (1,950 thou. tons) the amount systematically decreased. Among the voivodships the biggest volume of dust (82,5 thou. tons) was emitted from Katowice, whilst Opole voivodship was ranked on the seventh place (19,0 thou. tons).

Depending on the branch of industry, from which dusts derive they differ in toxic properties to plants. However, despite several studies considering this problem, a lot of questions are still not scrutinized.

It is well known that dust covers leaf blades or needles with a layer of various thickness which deteriorates the resistance of epiderm cells and chokes cuticles, limiting, in turn, gas exchange and transpiration, and disturbing life processes. Due to its physical-chemical properties and thickness of layer, the deposited dust 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 researchers 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. Generally, the most sensitive to dustiness are conifers and these species of deciduous trees that have leaves and shoots covered by hairs and cutin (Białobok 1989, Greszta 1987).

A retrospective ecological assessment of the pine defoliation in relation to age of trees and dust fall in their immediate environment is the aim of the presented research. In the analysis, the Bayesian statistical modeling was conducted in the BUGS software (Spiegelhalter *et al.* 1996) to estimate the unknown parameters of an assumed probabilistic model. The computation was performed for the region of Opole and some adjacent areas based on the monitoring data of the eighties and nineties. It is to stress that the paper pays more attention to flexible and extensive analytical opportunities provided by the applied Bayesian methods rather than to explicit biological aspects of the question under study.

MATERIALS

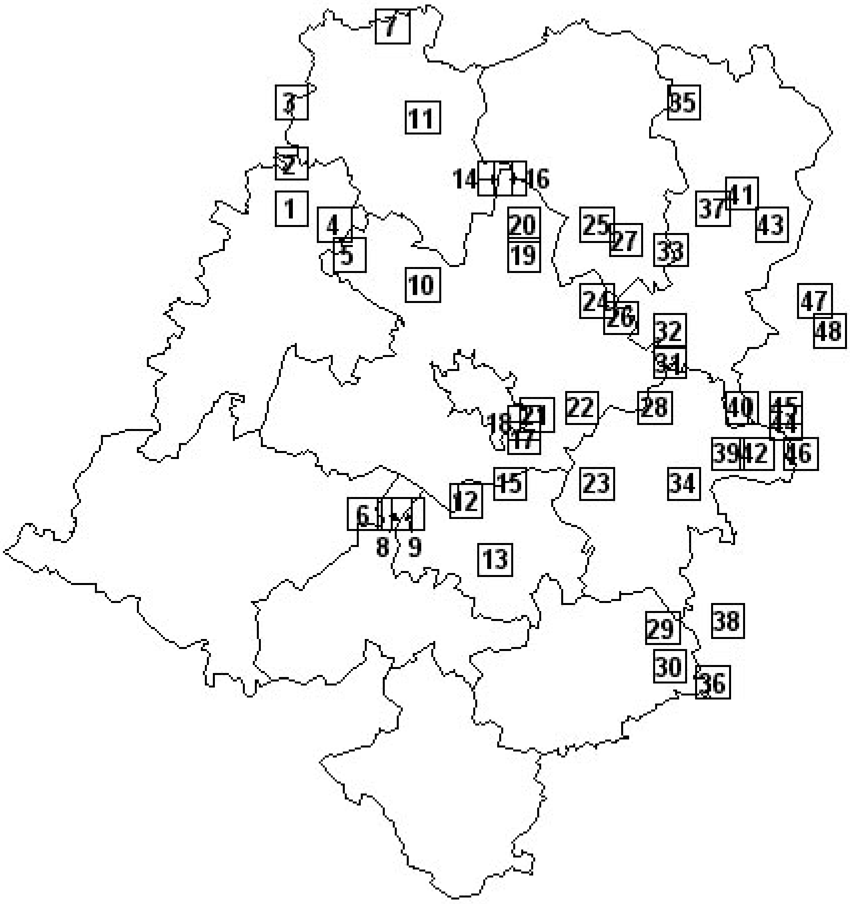
The following sets of geographical, biological and environmental information on pines within the analyzed POAs was used in this ecological study:

- their spatial locations,
- defoliation levels of the trees in the years 1989-1996,
- age, and
- dust fall at their immediate locations in the years 1988-1995.

The numerated geographical locations of the pine POAs in the region of Opole and some neighboring territories are presented in Figure 1.

Figure 1 shows that analyzed POAs are localized mainly in the central and north parts of the research surface – the most afforested territories in this part of Poland.

Figure 1. Locations of pine POAs in Opole region and some adjacent territories (numerated).



The POAs' geographical coordinates with the information sets on the defoliation measured in percentage of the total of needles ([%]) and the age of trees ([year]) are given in Table 1.

It can be calculated from the data provided in Table 1 that the largest average defoliation of the conifers was notified at POA 3 (almost 43 % defoliation), whereas the lowest value (on the level of approximately of 18 %) was observed at 26th POA. The latter value, however, concerns only the single annual measurement, thus this result might not have been fully credible. As regards the age of the pines in 1989, the oldest were 130 years old (POAs 28 and 35), while the youngest were 21 years of age (POA 12).

Table 1. Geographical and biological characteristics of Scotch pines in analyzed POAs.

POA	Geographical coordinates		Defoliation [%]								Age 1989 [year]
	Longitude	Lattitude	1989	1990	1991	1992	1993	1994	1995	1996	
1	17°31'52"	50°55'1"	26.75	27	36.25	36	38	37	36	32	71
2	17°31'52"	50°58'44"	14	19.75	36	36	37.5	35.25	n/a	n/a	66
3	17°31'52"	51°3'47"	40.25	42	42.5	42.75	44.5	46.5	44.25	41	90
4	17°37'30"	50°53'46"	18.75	20.25	37.25	37	38.75	36	35.5	31.25	55
5	17°39'22"	50°51'14"	27.5	25.25	39.75	40.5	42.25	41.25	n/a	n/a	71
6	17°41'17"	50°30'0"	28.75	30.75	31.5	32.25	41	n/a	n/a	n/a	71
7	17°45'0"	51°10'1"	29.25	30.25	35.75	37.25	37.5	34.75	38.25	33.75	66

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8	17°45'14"	50°30'0"	n/a	n/a	n/a	n/a	n/a	n/a	39	32.25	45
9	17°46'52"	50°30'0"	26	31.25	32.25	32.5	39.5	n/a	n/a	n/a	106
10	17°48'47"	50°48'47"	30.5	29.75	30.5	31.75	39.5	41	39.5	35.75	71
11	17°48'47"	51°2'31"	29.25	31	34.75	35	38.5	36.75	35	31.5	50
12	17°54'22"	50°31'8"	n/a	n/a	n/a	n/a	n/a	n/a	n/a	25	21
13	17°58'8"	50°26'17"	27.75	29.25	30.25	30.75	40.75	39	39	34.75	51
14	17°58'8"	50°57'29"	24.25	25	27.75	26	28.25	32.5	n/a	n/a	82
15	18°0'0"	50°32'31"	29.75	30.25	32	31.75	34.75	36.75	37.25	36.75	125
16	18°0'0"	50°57'29"	24.25	24.25	27.25	27.5	26.5	27.5	29	28	67
17	18°1'52"	50°36'14"	27.5	28.75	30.75	30.75	38.5	n/a	n/a	n/a	61
18	18°1'52"	50°37'30"	28	30	30.5	38.75	34.25	38	n/a	n/a	81
19	18°1'52"	50°51'14"	25.75	26.75	27.25	28	35.25	35.25	36.25	32.25	93
20	18°1'52"	50°53'46"	25.75	27	29.5	29.75	42	n/a	n/a	n/a	67
21	18°3'29"	50°38'10"	n/a	n/a	n/a	n/a	n/a	n/a	n/a	20.75	28
22	18°9'22"	50°38'46"	29.25	31	34.75	35	43	45.25	n/a	n/a	66
23	18°11'17"	50°32'31"	28	28.5	34	34	34.25	34.75	35.5	36	70
24	18°11'17"	50°47'31"	25	25	27.5	28.25	35.5	34.5	38.5	33.75	53
25	18°11'17"	50°53'46"	27.5	28.25	28.5	29	29.75	31.75	33.5	31.75	86
26	18°14'20"	50°46'8"	n/a	n/a	n/a	n/a	n/a	n/a	n/a	18.25	24
27	18°15'0"	50°52'30"	30.25	28.5	31	31	31	33.75	36	33	110
28	18°18'47"	50°38'46"	34.25	35.75	36.25	38.25	38	n/a	n/a	n/a	130
29	18°19'41"	50°20'38"	n/a	n/a	n/a	n/a	n/a	n/a	n/a	28.75	27
30	18°20'38"	50°17'31"	33.25	32.75	35.25	35.75	33	33.25	34.25	30.75	95
31	18°20'38"	50°42'29"	26.5	27.5	32.5	31.25	38.25	39.75	38.5	34.75	71
32	18°20'38"	50°45'0"	27.75	29.75	31.25	30	37.25	34	n/a	n/a	86
33	18°20'49"	50°51'40"	n/a	n/a	n/a	n/a	n/a	n/a	n/a	19.25	28
34	18°22'30"	50°32'31"	31.5	32.75	37.25	36	37.25	39.75	38.75	38.5	110
35	18°22'30"	51°3'47"	27.25	30	30.75	33.5	30.25	33.75	n/a	n/a	130
36	18°26'17"	50°16'16"	37.25	41.75	0	44	39.5	41.25	n/a	n/a	126
37	18°26'17"	50°55'1"	25.25	27	25	25.75	32.75	n/a	n/a	n/a	72
38	18°28'8"	50°21'14"	31.25	31.25	34.75	35.25	35.25	38	38	35.25	55
39	18°28'8"	50°34'59"	21.25	21.25	39.75	38.5	40	41.5	41	37.75	43
40	18°30'0"	50°38'46"	30.5	30.25	39.75	40	42.25	42.25	40	37.5	118
41	18°30'0"	50°56'17"	31.25	33.75	31.25	31.5	31.75	36.75	36.75	32.75	86
42	18°31'52"	50°34'59"	26.5	26.5	32.75	30.5	30.5	33.5	n/a	n/a	58
43	18°33'47"	50°53'46"	24.75	26.75	26.75	26.5	30.25	35	36	33.75	77
44	18°35'38"	50°37'30"	19.25	19.25	23.25	24	28	33	n/a	n/a	57
45	18°35'38"	50°38'46"	24.5	24	26.75	27.25	28.75	29.75	n/a	n/a	102
46	18°37'30"	50°34'59"	22.75	22.25	31	31	30.25	36.25	35.75	33.25	53
47	18°39'22"	50°47'31"	24.75	25.75	28.75	31.75	37.25	38	n/a	n/a	110
48	18°41'17"	50°45'0"	27.75	27.75	29	29	33.5	36.75	37	35.75	55

The spatial distributions of dust fall measured via the sedimentation method and expressed in grams for a square meter for a month ([g/(m^2×month)]) in the research rectangle surface in succeeding years from 1988 to 1995 are presented in a small scale in maps in Figure 2.

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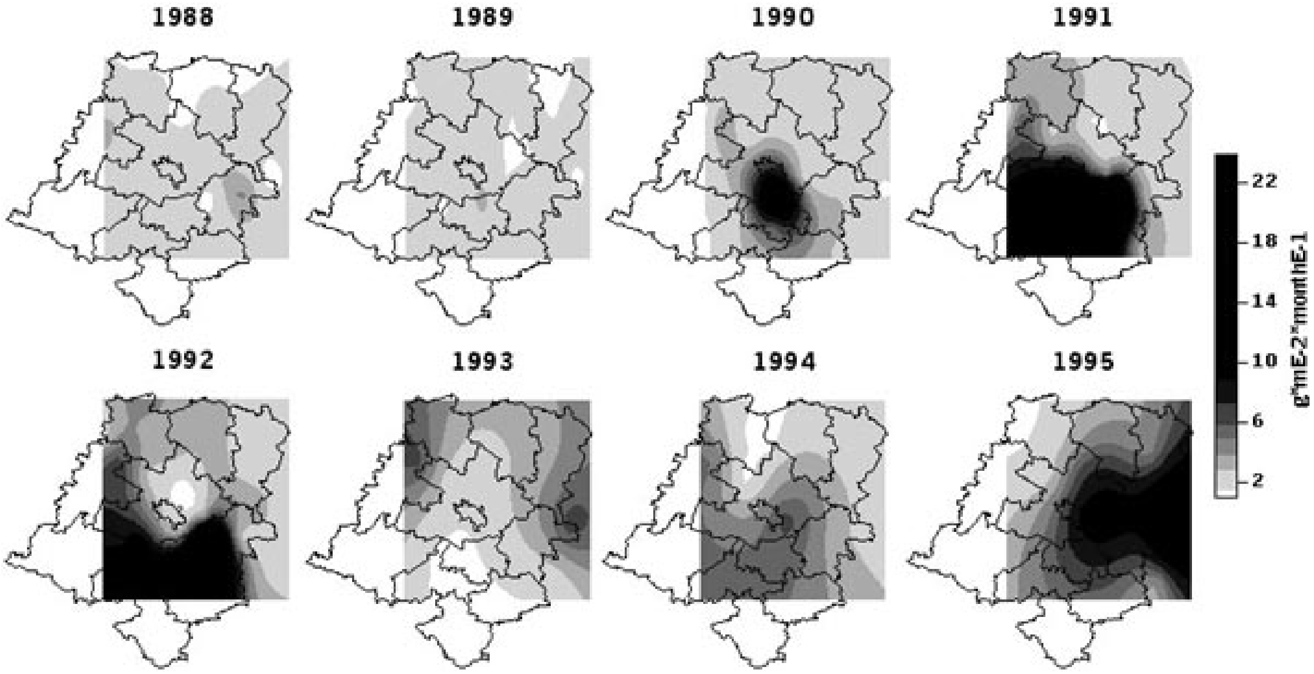
The maps in Figure 2 show fairly chaotic patterns of dust fall intensities in the research surface and the period considered, i.e. a quite continuous increase of dust fall in the years 1988-1991, an apparent decrease in 1993 and 1994, as well as the locally changeable dust falls across the study rectangle.

Figure 2. Dust fall in research surface in the years 1988-1995.



METHODS

A one-year latency between a cause-specific effect of the environment and a biological reaction of the trees was assumed in the study. Consequently, the periods for the defoliation and for the dust fall processes were transited in relation to each other.

The estimation of dust fall in the 1988-1995 period for the locations of pines was performed via a standard kriging method (Keckler 1995: chapter 5-32) from the form-fitted interpolations grids for the considered rectangle research surface. After completing all data sets of interest, an appropriate putative mathematical relation between the considered biological and the environmental processes was initial for further Bayesian statistical modeling. Some brief notes over the Bayesian approach in statistics might be mandatory for those who are not involved in such an ecological assessment methodology.

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) (Boczarow 1976).

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Such analyzed (consistently with modern statistical trends) phenomena result in the creation of many universal computational methods. In the recent years, among revolutionary achievements in ecology, the application of Bayesian methods together with Markov chain Monte Carlo (MCMC) techniques are of special note (see: e.g. Smith and Roberts 1993). The basic philosophy behind MCMC is to take a Bayesian approach and to carry out 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) (see: Metropolis *et al*. 1953, Hastings 1970, Geman and Geman 1984, Smith and Roberts 1993 for details). In the 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 to compute the 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, to monitor the stream for convergence, and to summarize the accumulated samples (see: e.g. Smith and Roberts 1993 for details).

Based on this methodology, a number of computer programs were created, among which BUGS ("Bayesian Inference Using Gibbs Sampling") – a noncommercial software of the Medical Research Council – Biostatistics Unit in Cambridge, UK – is one of the leading and most popular MCMC Bayesian statistical tools (Spiegelhalter *et al*. 1996).

In the statistical modeling of the studied problem, it was assumed that the defoliation of Scotch pines in the succeeding years 1989-1996 was a combination of linear functions of the age of trees and dust fall at their locations in subsequent years from 1988 to 1995. In the research the assumed probabilistic model for the 48 pines and the 8-year period was expressed by the following statistical description (a general form):

$$\begin{gathered}\textbf{for i = 1, …, 48 (pines) and j = 1, …, 8 (years)}\\ \mathbf{defoliation_{ij} \sim Normal(nu_{ij},\ sigma)}\\ \mathbf{nu_{ij} = alpha_{ij} + beta_1 \times age_{ij} + beta_2 \times dust.fall_{ij}.}\end{gathered}$$

The estimation of the unknown alpha_{ij}, beta_1 and beta_2 parameters allow to plot the modeled defoliation of pines in relation to the age of trees and the dust fall at their locations.

The map of the analyzed POAs' locations was created in MapInfo 4.5 package. The spatial distributions of dust fall in the research surface were created in SURFER 6.0 program. The same program was used to calculate the dust falls at the immediate locations of trees. The estimation of the unknown model's parameters was performed in the WinBUGS 1.3 software. The scatterplots of the results were presented via S-PLUS 4.0 and SURFER 6.0 packages.

RESEARCH RESULTS

The results of the posterior Bayesian analysis for the assumed statistical model's parameters beta_1 and beta_2 are set in Table 2 (in the study, the computation based on a burn in of 1,000 iterations and following 10,000 production run samples provided convincing evidence of converged distributions of the streams of values during the Gibbs sampling).

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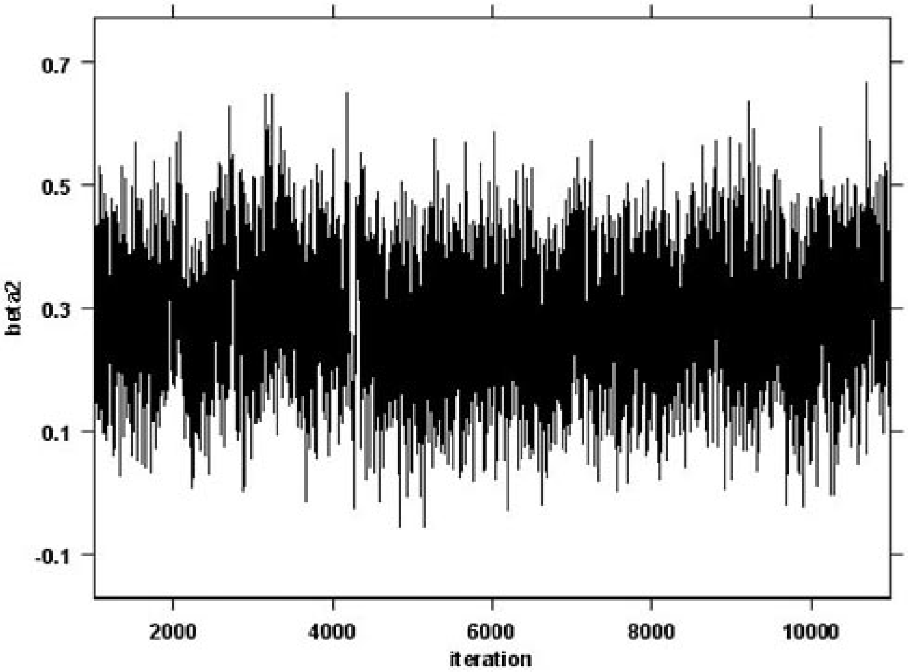
Table 2. Posterior analysis of model's beta1 and beta2 parameters.

Parameter	Mean	Standard deviation	Credible 95 % intervals
$beta_1$	0.040	0.01052	(0.02267, 0.06512)
$beta_2$	0.285	0.09811	(0.09515, 0.48040)

Based on the obtained standard deviations of simulated values, the stability of means for these 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 ($beta_2$) is presented in Figure 3.

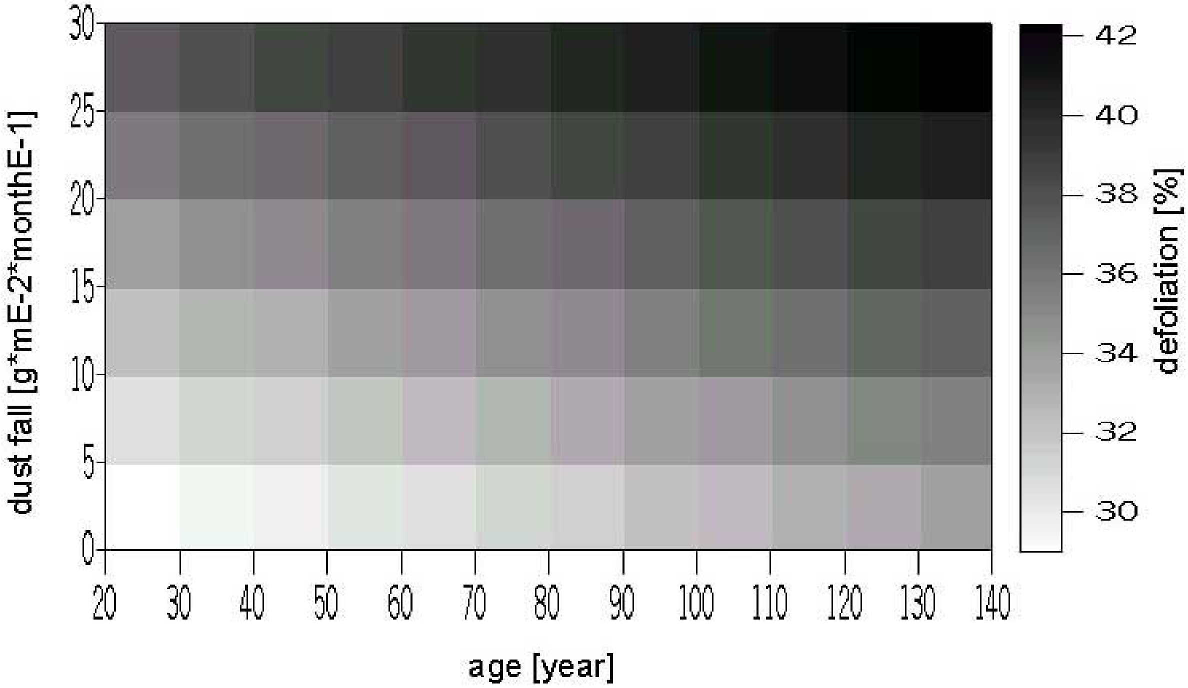
Figure 3. Trajectory of simulated values of beta2 parameter versus iteration steps.



CONCLUSIONS

The above statistical results using the Bayesian approach allow for a graphical distribution of the defoliation of the analyzed pines as a function of the age of trees and the dust fall at their locations. The map of such relations based on the achieved results is presented in Figure 4.

Figure 4. Defoliation of pines versus age of trees and dust fall



The analysis of the map in Figure 4 clearly shows that the defoliation process of needles of the conifers observed in the years 1989-1996 increased with the age of pines and the dust fall at the trees' locations in the preceding period of 1988-1995. This fact may lead to a certain speculation over the etiology of the health deterioration of the studied Scotch pines *Pinus silvestris* L. and especially over the significant positive contribution of the environmental pollution, i.e. dust fall. 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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