FIRST INTERNATIONAL CONFERENCE ON MEASUREMENTS AND MODELLING IN ENVIRONMENTAL POLLUTION
MMEP 97

CONFERENCE DIRECTORS

R. San José
Technical University of Madrid

C.A. Brebbia
Wessex Institute of Technology

Organised by:

Wessex Institute of Technology, UK
&
Environmental Software and Modelling Group of UPM, Spain

Thanks are due to V. Klein, J. Roths and B. Hilber for the use of Figure 4 on page 362 which appears on the front cover of this book.

Measurements and Modelling in Environmental Pollution

Computational Mechanics Publications
Southampton, UK and Boston, USA

R. San José
Environmental Software and
Modelling Group
Computer Science School
Technical University of Madrid
Campus de Montegancedo,
Boadilla del Monte - 28660
Madrid, Spain

C.A. Brebbia
Wessex Institute of Technology
Ashurst Lodge
Ashurst
Southampton
SO40 7AA, UK

Published by

Computational Mechanics Publications
Ashurst Lodge, Ashurst, Southampton, SO40 7AA, UK
Tel: 44(0)1703 293223; Fax: 44(0)1703 292853
E-Mail: cmp@cmp.co.uk
WWW: http://www.cmp.co.uk

For USA, Canada and Mexico

Computational Mechanics Inc
25 Bridge Street, Billerica, MA 01821, USA
Tel: 508 667 5841; Fax: 508 667 7582
E-Mail: cmina@ix.netcom.com

British Library Cataloguing-in-Publication Data

A Catalogue record for this book is available
from the British Library

ISBN 1 85312 461 3 Computational Mechanics Publications, Southampton

Library of Congress Catalog Card Number 97-65935

The texts of the various papers in this volume were set individually by the authors or under their supervision

No responsibility is assumed by the Publisher, the Editors and Authors for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions or ideas contained in the material herein.

Printed and bound in Great Britain by Anthony Rowe, Chippenham, Wiltshire.

Application of the generalized state index determination to ecological monitoring of forests in polluted areas

S.A. Shavnin , V. V. Fomin & N.V. Marina
Department of Applied Physics & Biophysics, Urals State Forestry Engineering Academy , Ekaterinburg, 620032 , Russia
Email : shsa@ulti.mplik.ru

Abstract

A new kind of quantitative model for assessment of state of Scotch pine tree stands growing in industrial polluted areas of Middle Urals is desribed. The model is based on the use of two types of indices - state indices and generalized state indices - which are calculated from morphological and physiological characteristics (parameters) of tree stands. Morphological parameters include average values of tree diameters, heights, and annual increments while physiological characteristics include chlorophyll a content and photochemical quantum yield of photosystem II in pine needles. It is shown that the use of the combination of diagnostic parameters as in the model described provides more credible assessment of tree stands state than the use of separate diagnostic characteristics.

1 Introduction

The proper ecosystem state assessment evaluating proved to be of first rate importance in ecological monitoring of polluted areas. To assess an ecosystem state it is necessary to develop a set of quantitative diagnostic characteristics or state indices which allow to evaluate industrial pollution effect on particular components of the ecosystem. Besides, the necessity exists for a kind of generalized state index derived from this set of state indices to assess industrial pollution effect on the whole ecosystem. The generalized state indices or environmental indices (Alberti & Parker [1]) can be used in social policy decision making as well as in study of natural objects' stability criteria. All kinds of indices are usually derived from experimental and empiric data arrays by applying data and information contraction methods to these arrays (Vorobeychik et al. [2]).

One of promising methods of contracting information on tree stands state is based on the use of the generalized Harrington desirability function (Adler et al. [3] , Kalinin et al. [4]). Unlike conventional methods, this one makes it possible to take into account nonlinearities which are peculiar to characteristics used in ecotoxicology. In addition, since the "desirability " concept is based on the use of dimensionless quantities, the method allows to assess the ecosystem's state on the average on the basis of complete set of diagnostic characteristics (parameters). Since the primary productivity of an ecosystem depends on photosynthesis, the growth characteristics as well as the photosynthetic apparatus characteristics of dominant woody species of a particular tree stand can be regarded as the most essential ones in assessment the tree stand state (the forest state). It has been shown for pine forests of the Middle Urals that average values of diameter, height, and annual increment of pine trees should be used as the essential parameters to assess the tree stands state. Also chlorophyll a and b content is one of the important parameters which is intimately bound up with the photosynthetic apparatus state. The most of gaseous and atmospheric pollutants decrease it (Dietz et al. [5] , Snel et al. [6] , Kirpichnikova et al [7]).

In the Middle Urals forests chlorophyll destruction by pollutants takes place throughout the year cycle but there are also additional distinctive seasonal changes in photosynthetic apparatus (Krivosheeva et al. [8] , Shavnin & Fomin [9] , Shavnin et al. [10]).

Chlorophyll fluorescence characteristics measurement is one of the most promising approach to the photosynthetic apparatus state assessment in ecological monitoring. The widely used parameter F_v / F_{max} , which value reflects the efficiency of noncyclic electron transport process in chloroplasts is declined in the needles of *Picea abies(L.)* under the effect of the set of air pollutants (Bolhar - Nordenkampf et al. [11]). Recently developed modulated light fluorimeters designed for laboratory and field applications (PAM 2000, Walz, Germany) made it possible to measure this parameter in both laboratory and field studies.

This paper concentrates on assessment of the prospects of application of generalized state index , derived from the morphometric data and photosynthetic apparatus parameters, in ecological monitoring of pine tree stands growing in air polluted regions.

2 Materials and Methods

During 1995 - 96 we studied the state of 20 - 40 years old artificial pine tree stands of *Pinus silvestris (L.)* located in air polluted areas around cities of Revda and Pervouralsk (the Middle Urals , Sverdlovsk region , Russia). The main source of industrial pollution in the region is the large copper-smelting plant SUMZ located in the city of Revda. Some additional sources of air pollution are located in the city of Pervouralsk which is a large industrial center NE of Revda (at six kilometers' distance from Revda). Westerly and north-westerly winds usually prevail throughout the region.

The thirty plots were settled and described morphologically. All these plots had been combined into four transects (NE, E, SE and NW of SUMZ). The plot 20 located at twenty-six kilometers' distance from SUMZ (SW of SUMZ) was accepted as the control one, which exhibits the natural background pollution value. The same woody, shrub and grass species dominate within all the settled plots. Recommendations on choosing plots and methods of measurement of diameters, heights , vertical increments and chlorophyll a content in two - year pine needles have been described earlier (Krivosheeva et al. [8], Schawnin et al. [12].

Since the different tree stands under investigation were of different age, the extrapolation of diameters and heights from measured values to those typical for a 30- year pine tree has been performed. In both fluorescence characteristics measurement and pigment analysis two -year pine needles picked up from the same shoots were used. The needles were picked up from fifteen trees of the same plot (one shoot from a tree , one measurement for a shoot). The results of measurement for each plot were processed statistically.

After cutting, sprinkling with water and putting into plastic bags, the shoots were carried to the laboratory. The fluorescence measurements were taken the next day after the day of cutting shoots. For adaptation purposes, shoots were placed vertically into glass containers filled with water and then exposed for 45 minutes at the temperature of 22 - 24° C and the constant photon flux density (PFD = 50 µmol quanta $m^{-2} s^{-1}$). After that, four needles still attached to the shoot, were placed horizontally into the Leaf - Clip Holder 2030 - B (Walz, Germany) and exposured additionally for 3 minutes at the same photon flux density. The fluorescence characteristics were measured by means of the fluorimeter PAM - 2000 (Walz, Germany). These characteristics include F_t (measuring light - induced fluorescence value) , F_m' (saturating light - induced peak fluorescence value) and the " Yield " parameter which value is related to the Photosystem II quantum yield of fluorescence : Yield = $(F_m' - F_t) : F_m'$.

The generalized state indices for tree stands were calculated by applying the method of geometric means to state indices which had been calculated on each particular characteristic separately. These state indices were taken to be equal to their desirability values which had been calculated using the Harrington' s formula (Adler et al [3]) :

$$d_i = 100 \exp [- \exp (- y_i')] ,$$

where d_i - desirability value of i-th parameter ;

y_i' - encoded value of i-th parameter.

The linear equations were used to encode the measured characteristics of particular objects as it was shown for the earlier model (Kalinin et al. [4]). However, since the weight assigned to a particular parameter used in calculating particular generalized state index depends on the normed deviation value t, the earlier model has been modified to make more unbiased choice of t. Namely, the procedure of choosing reference values which are used to define the function $d_i = f(y_i')$ has been changed. The first reference value is specified as follows : $d_{1i} = 63$, $y_i' = 0.75$, while the second reference value which define the " poorest " state is specified as follows : $d_{2i} = 5$, $y_i' = -1.1$.

The measured value of a particular parameter for the control plot is taken as corresponding to the first reference value. Then the measured values of the same diagnostic parameter for all sample plots are analyzed to find the lower-range parameter value . This value is assumed to correspond to the second reference value. Since the obtained y' - scale is linear, the specifying of the two reference values makes it possible to encode diagnostic parameters measured for the rest of sample plots. The increase in d_i means upgrading the object's characteristic on i-th parameter.

3 Results and Discussion

Measured values for different variables (y_i) for control plot's tree stands (y_{1i}) are given in Table 1 together with their lower-range values (y_{2i}) for sample plots' tree stands.

Table 1 Morphological and Physiological Characteristics of Pine Tree Stands for Control Plot (y_{1i}) and Plots Ranked as "Poorest" of All Sample Plots (y_{2i}), $X \pm \sigma$.

	Average diameter, cm	Average height, m	Diameter increm. for 5 years, mm	Height increm. for 5 years, m	Chlorophyll a content, mg/g dry weight	Fluor. param. Yield, rel.units
y_{1i}	17,4±0,8	14,0±0,4	8,7±2,9	2,6±0,2	2,33±0,35	0,67±0,03
y_{2i}	6,2±0,6	6,45±0,62	3,0±1,1	0,4±0,1	1,21±0,24	0,61±0,01

The differences between y_{1i} and y_{2i} are reliable (with $P = 0.99$). The average diameter, height, and chlorophyll a content take on their lower-range values at the plot 7, average diameter increments for the last five years - at the plot 113, and " Yield" parameter - at the plot 99. In other words, the tree stands states for these plots are assessed as very poor according to these parameters. The fact that the lower-range values of different diagnostic parameters are relevant to different plots gives evidence of the necessity for a whole set of parameters in evaluation of tree stands state.

Since the growth and physiological processes in trees of the same plot are influenced by a unique combination of factors, and the balance of recovery and suppressing processes is unique for each plot, a special set of diagnostic parameters must be used to assess all essential features of the object in study. It is reasonable to suppose that three of six characteristics of the plot 7 take on their lower-range values because air pollutants are easily conveyed with prevailing winds from nearby cities of Revda and Pervouralsk to this plot, and it is actually located in the most polluted region.

The plot 113 is located at two kilometers' distance from Revda and is affected by pollution from SUMZ and some other local plants as well. The plots 99 and 100 are located not far from Reshety, the large road and railway junction. These factors provide a specific kind of pollution for the area under investigation.

The data presented in Table 1 were used to obtain dimensionless values y_i as well as to calculate state indices d_i (see also the section "Materials and Methods").

The Table 2 presents tree stands state indices calculated on particular morphometrical characteristics by the four transects. The state indices calculated on physiological characteristics as well as generalized state indices over the whole set of characteristics by the four transects are presented in Table 3. The data analysis reveals that in terms of average diameter values the tree stands of the control plot are the best. Table 2 also shows that for most sample plots the state indices calculated on height and vertical increment values are higher than those calculated on diameters and diameter increments. This suggests that cambium growth processes are more affected by pollutants than apical meristem growth processes.

For NE transect the state indices values of the most of diagnostic characteristics (parameters) increase as the distance from SUMZ increases. Since the plots 3 and 5 are shielded by some local hills from the sources of pollution, it is reasonable to suppose that relatively high values of generalized state indices calculated on physiological characteristics - 56 for the plot 3 and 57 for the plot 5 - can be attributed to the lower influence of gaseous pollutants on the tree stands. The tree stands states for plots along E- direction can be described as good starting with the plot 96. Besides the distance from SUMZ, the decreasing of pollution effect on tree stands states also depends on the relief : the Volchikha hill (526 m above sea level) and the Grebni hills (440 m above sea level) shield the plot 96 as well as other neighboring plots from the sources of pollution. The plots 129, 100 and 99 are affected by Reshety pollution source mentioned above.

As for the tree stands along SE - transect, their generalized state indices based on morphological characteristics are low and relatively stable. In contrast, their generalized state indices calculated on physiological characteristics of the pine needles' photosynthetic apparatus are relatively high.

The analysis of tree stands of NW- transect reveals upgrading their states as the distance from SUMZ increases.

It is important that at fourteen to sixteen kilometers' distance from SUMZ the generalized state indices calculated on the whole set of the measured characteristics is higher than 50 and is close to the control value of this index, but this is not true for other transects (Table 3).

Table 2 Pine Tree Stands State Indices Calculated on Particular Morphological Characteristics by Selected Transects

plot #	Distance from SUMZ, km	Diameter	Height	Diameter increment for 5 years	Height increment for 5 years
			NE- transect		
7	4,1	5	5	15	24
3	9,7	14	38	37	52
5	12,3	22	44	20	33
126	17,2	41	68	22	37
53	26,6	33	21	78	53
55	28,0	33	59	79	57
			E-transect		
88	5,6	16	32	7	19
92	6,9	31	43	7	9
96	12,0	26	53	22	49
97	12,6	15	51	80	57
131	17,2	33	62	59	71
129	17,5	27	55	15	23
100	20,5	41	37	11	5
99	20,9	31	48	13	32
			SE-transect		
6	3,1	35	68	14	29
113	10,0	31	78	5	42
112	10,1	31	73	9	48
81	14,5	21	46	41	46
85	16,0	25	48	19	34
82	16,7	41	64	20	66
120	18,2	13	36	21	27
121	19,9	39	46	43	29
122	21,6	19	38	51	48
			NW-transect		
16	4,2	15	31	12	29
13	9,5	50	56	13	60
12	12,1	30	59	24	47
37	14,5	26	59	32	59
39	14,5	32	47	76	56
40	16,7	59	72	29	53
			Control		
20	18,9	62	62	62	62

Table 3 Pine Tree Stands State Indices Calculated on Particular Physiological Characteristics and Generalized State Indices (GSIs) by Selected Transects

plot #	Chlorophyll a content, mg/g, dry weight	Fluorescent parameter Yield, rel. units	GSIs		
			morphol.	physiol.	total
		NE-transect			
7	5	48	10	15	12
3	48	66	32	56	39
5	66	50	28	57	36
126	66	16	39	33	37
53	23	70	41	41	41
55	55	54	54	54	54
		E-transect			
88	55	22	16	34	21
92	36	46	17	41	22
96	64	45	44	50	46
97	71	34	44	50	46
131	49	60	54	54	54
129	62	47	27	54	34
100	24	15	17	19	18
99	62	28	28	18	24
		SE-transect			
6	30	60	31	42	35
113	73	54	27	63	35
112	76	45	32	58	39
81	53	69	37	60	43
85	62	56	30	59	37
82	74	47	43	59	48
120	70	46	23	56	31
121	64	65	39	64	46
122	64	66	36	65	44
		NW-transect			
16	62	27	20	41	25
13	81	50	38	63	45
12	68	37	38	51	41
37	60	39	42	49	44
39	75	77	50	76	58
40	72	56	50	64	55
		Control			
20	18,9	62	62	62	62

The comparison of the two types of generalized state indices (Table 3) reveals that "physiological" indices as a rule are higher than "morphological " ones. In our opinion, there are two possible ways to explain this fact. One explanation is as follows. The "physiological" characteristics of photosynthetic apparatus in pine needles were measured in the end of the second vegetation period. It is reasonable to suppose that during this period the changes in "physiological" characteristics did not attain their maximal values and were lower than the changes in "morphological" characteristics. Another explanation takes into account environmental changes within the last 3- 5 years. Because the local industry was depressed during this period, the industrial pollution was reduced.This resulted in recovery of pine needles' physiological characteristics. Nevertheless,the growth recovery did not take place.

It is reasonable to suppose that the depressed processes of mineral nutrition are responsible for the growth depression. Taking into account that the accumulation of heavy metals and other toxic pollutants by local soils took place over the long period of time (more than fifty years) , the self-purification of soils and related processes of recovering mineral nutrition will take more time than the self-purification of the atmosphere. Consequently, growth recovery which depends on mineral nutrition will take more time than " physiological " recovery which mostly depends on the air pollution level.

The authors believe that the method of assessment tree stands state using proposed set of characteristics (GSI total) is quite sensitive and credible . Besides evident effect of large pollution sources on tree stands state it allows to reveal the effect of local man-made pollution sources . The authors suppose that the use of generalized state indices is promising in ecological examination and forest mapping.

Acknowledgements

The authors thank Dr. C. Scheidegger and Dr. W. Bilger for useful discussion on fluorescence measurement techniques and supporting the work, Dr. I. Usupov, Dr. Z. Nagimov and Dr. Yu. Alesenkov for their participation in measurement of morphological characteristics of tree stands. The presented results have been obtained within the INTAS 93-1645 Project supported by INTAS Foundation , Brussels.

References

1. Alberti, M. & Parker, J. D. Indices of environmental quality. The search for credible measures, *Environmental Impact Assessment Review*, 1991, **11**, 771- 775.
2. Vorobeychik, E. L. , Sadykov, O. F. & Farafontov, M. G. *Ecological*

Standartization of Terrestrial Ecosystems Technogenic Pollution (Local Scale), Nauka, Ekaterinburg, 1994 (in Russian).

3. Adler, Yu. P., Markova, E. V. & Granovsky , Yu. V. *Experiment Design in Seeking Optimum Conditions*, Nauka, Moscow, 1976 (in Russian).
4. Kalinin, V.A., Kryuk, V. I. , Luganskii, N. A. & Shavnin, S. A. Model for assessing status of damaged tree stands, *The Soviet Journal of Ecology*, 1991, **22**, 149 - 154.
5. Dietz, B., Moors, I., Flammersfeld, U., Ruhle, W. & Wild, A. Investigation on the photosynthetic membranes of spruce needles in relation to the occurrence of novel forest decline . 1.The photosynthetic electron transport , *Zeitschrift Naturforschung*, 1988, **43C** , 581 - 588.
6. Snel, J.F.H., van Kooten, O. & van Hove, L.W.A. Assessment of stress in plants by analysis of photosynthetic performance, *Trends in Analytical Chemistry*, 1991, **10** , 26 - 30.
7. Kirpichnikova, T. V., Shavnin, S. A. & Krivosheeva, A. A. Photosynthetic apparatus in the needles of pine and spruce grown in areas of industrial pollution under different microclimatic conditions, *Russian Journal of Plant Physiology*, 1995, **42**, 94 - 99.
8. Krivosheeva, A. A., Shavnin, S. A., Kalinin, V. A. & Venedictov, P. S. Effect of industrial pollutants on seasonal changes of chlorophyll content in Scotch pine needles, *Soviet Plant Physiology*, 1991, **38**, 126 - 130.
9. Shavnin, S. A. & Fomin, A. S. Seasonal changes in the chlorophyll fluorescence of Scotch pine needles, *Soviet Plant Physiology*, 1993, **40**, 176- 180.
10. Shavnin, S. A., Kirpichnikova, T. V. & Krivosheeva, A. A. The effect of polyethylene glycol on chlorophyll fluorescence of chloroplasts isolated from Scotch pine needles, *Russian Journal of Plant Physiology*, 1995 , **42**, 786- 790.
11. Bolhar - Nordenkampf, H. R., Long, S. P., Baker, N. R., Öquist, G., Schreiber, U. & Lechner, E. G. Chlorophyll fluorescence as a probe of the photosynthetic competence of leaves in the field : a review of current instrumentation, *Functional Ecology*, 1989, **3** , 497 - 514.
12. Schawnin, S., Kalinin, V. , Sweschnikow, V. & Motschalow, S. Bewertung des Gesundheitszustandes von Föhren - Jungbeständen im immissionsbelasteten Gebiet des Mittel - Urals, *Schweizerische Zeitschrift für Forstwesen (Journal Forestier Suisse)*, 1995, **146**, 829 -836.