SELECTION OF INDICES FOR THE MONITORING OF SPRUCE FORESTS WITHIN IMPACT ZONE OF THE METALLURGICAL ENTERPRISE

TATIANA TOKAREVA[1] and DMITRY SCHEPASCHENKO[2*]
[1] *Moscow State Forest University, 141001, Mytischi, Moscow region, Russia. Present address: 400093, ul. Tankistov, 4–48, Volgograd, Russia;* [2] *Moscow State Forest University, 141001, Mytischi, Moscow region, Russia*
(author for correspondence, e-mail: dschep@mgul.ac.ru)*

(Received 28 June 1999; accepted 23 September 1999)

Abstract. We established a number of sample plots within the limits of Norway spruce stands featured by different levels of digression on the territory influenced by 'Severonickel' smelter. A series of morphological, physiological and biochemical parameters of spruce stands was measured. In applying statistical methods, an interpretation was made on the reaction of stands to different contamination levels, the interdependence of individual indices, as well as to select bioindication indices to be recommended for monitoring realization. The following indices are recommended: morphological (weight of 100 dry needles), physiological (rate of water loss after wilting 4 h) and biochemical (content of pollutants, i.e., nickel, copper and sulphur in the needles) indices. The equations expressing dependencies between bioindication parameters and indices of stand condition are also adduced.

Keywords: monitoring of forest, pollution, spruce forest

1. Introduction

The danger of moderate contamination doses exists in chronic disturbances of ecosystems, and in permanent extensions of areas covered with weakened and dissociated stands. The signs of any disturbance will become visible after the ecosystem buffer mechanism have been disturbed by slowly accumulated changes, i.e., when degradation of the system begins (Smith, 1985). Our work investigates the influence of different doses of atmospheric pollution upon changes in the morphological, physiological and biochemical parameters of spruce stands growing in the Cola peninsula. We have also investigate bioindication indices of needles as indicators of environments pollution and the state of Norway spruce trees during the early stages of being damaged, as well as to develop a prognostic model for monitoring spruce forests.

Water, Air, and Soil Pollution **121:** 339–347, 2000.

2. Material and Methods

The investigations were carried out for spruce stands, which were exposed to technogenic emissions from the ‘Severonickel’ smelter complex direction.

While assessing the degradation of forest stands influenced by technogenic pressure, the following zones of digression are distinguished (Karaban’ and Rudneva, 1988). The complete digression of stands zone (I) presents a technogenic desert with vegetation fragments available. The dying trees with very thin crowns, as well as top-drying crowns, prevail. Stunting and bushiness of trees are characteristic features, box regeneration is lacking. The high digression zone (II) is remarkable for a uniform distribution of living trees over the total area. The share of drying and top-dry trees amounts to 40 per cent, and only single cases of regeneration takes place. The average digression zone (III) is characterized by thin forest stands with a density of 0.4 to 0.5. The share of top-drying and deadwood trees reaches up to 10 per cent, while young growth and underbrush are satisfactorily developed. The needles are green in color with separate chlorosis bunches. The faint digression zone (IV) does not differ (according to distinguishable signs) from stands that were not subjected to industrial emission. The maximum single concentrations of SO_2 in the air were measured in each digression zone. The check plots were establishedwithin undamaged forest stands where the sulphur dioxide content in the air did not exceed background levels.

The following forest estimates and forest pathological characteristics describing the state of spruce stands in different digression zone were determined: class of tree growth (according to Kraft); category of the sanitary state of the stands; degree of air pollution; maximum single concentrations of sulphur dioxide in the air; accumulation of sulphur in the snow; characteristics of the assimilation apparatus – number of needles per 1 sm. of shoot length, shoot length, number of needles at the shoot, weight of 100 fresh cut or completely dry needles, water content of the needles, water content of the needles per unit of dry weightm, water-holding capacity of the needles measured after wilting for 2, 4 and 24 h (Nichiporovich, 1926); content of sulphur (Maslov, 1978) and metals (including nickel, cobalt, copper, zinc, iron, lead, aluminium, cadmium, lithium, etc.) in the needles measured using an atomic absorption spectrophotometer.

Standard correlation analysis, as well as gegression analysis, has been applied in this work. In order to find out informative signs, the methods of automated classification have been used (Rozhkov, 1989). Similarity between objects was calculated by following equation.

$C_{lt} = (1 - d_{lt}^2)^{-1}$, where

d_{lt} – distance between the objects 1 and t;

$$d_{lt} = \frac{1}{q} \times \left(\sum_{j=1}^{q} \frac{(x_{lj} - x_{tj})^2}{S_j^2} \right)^{1/2}, \text{ where}$$

TABLE I

Contents of sulphur in the ecosystem components for the different zones of forests stand digression

Zone of digres-sion	Maximum single concentrations of $SO_{2.}$ in the air, mg/m^3	Sulphur content in the ratio to dry weight, %					
		soil	lichens	spruce		birch	
				needles	bark	foliage	bark
I	0.16–0.30	0.388	–	0.431	0.219	0.750	0.275
II	0.14–0.20	0.626	0.650	0.471	0.560	1.225	0.213
III	0.08–0.13	0.275	0.508	0.414	0.171	1.000	0.219
IV	0.06–0.09	0.300	0.588	0.214	0.154	0.500	0.213
check plot	0.04–0.06	0.156	0.315	0.224	0.169	0.325	0.159

q – number of signs;
x_{lj} – meaning of the j-sign for l-object;
S_j – standard deviation of the j-sign;

$$S_j^2 = \frac{1}{n-1} \times \sum_{i=1}^{n} (x_{ij} - x'_j)^2, \text{ where}$$

n – number of objects;
x_{ij} – meaning of the j-sign for i-object;
x'_j – mean of the j-sign.

3. Results and Discussion

Our investigations have shown that an accumulation of excessive amounts of sulphur takes place in the different components of ecosystem influenced by industrial emission (Table I). The content of cobalt within the upper organic soil horizon at the area situated in a high digression zone amounts to 0.0231 mg/g, whereas this index is reduced to 0.0052 mg/g at the check plots; the respective data for copper amounts to 0.7277 mg/g and 0,0130 mg/g correspondingly, and for nickel 0.6579 mg/g and 0.0083 mg/g correspondingly.

The contents of cobalt, copper, nickel, lead and zinc in lichens growing at the check plots amount to 0.010, 0.004, 0.009, 0.014 and 0.026 mg/g respectively. The accumulation of metals by the needles of Norway spruce increases directly proportional to the concentration of pollutants (Table II).

TABLE II

Contents of metals in the needles of Norway spruce

Zone of digression	Content of metals, mg/g				
	Ni	Co	Cu	Zn	Pb
I	0.0810	0.0020	0.044	0.474	1.032
II	0.0580	0.0020	0.029	0.103	0.003
III	0.0289	–	0.009	0.036	–
IV	0.0153	0.0015	0.002	0.068	0.002
check plot	0.0050	0.0012	0.004	0.046	0.004

A reduction in the needles' lifetime and a decrease of photosynthetic activity are registered fir the zones with a high content of sulphur dioxide. We have analyzed the fresh and dry weights of 100 needles of Norway spruce and the functional dependence between air pllution and accumulation of phytomass by the needles has been ascertained. The dresh weight of 100 annual needles decreases for 0.718 g at the check plots to 0.558 g within a complete digression zone. A similar situation is observed while analyzing the dry weight of 100 needled; it decreases from 0.536 g at the check plots to 0.252 g within a complete digression zone (i.e., a two-fold reduction occurs).

We have studied the water regime of the needles in different contamination zones, and it has been ascertained that the water contents of one-year-old and five-year-old needles within check plots amounts to 46.8 per cent and 40.4 per cent respectively; withina complete digression zone the respective indices are equal to 43.8 and 29.6 per cent correspondingly. The change in the water-holding capacity of the needles depends directly on the degree of air pollution. Within a complete digression zone, the spruce needles lose 16 per cent of initial moisture, i.e. 2.5 times as much as at the check plots (6 per cent) (Figure 1).

The morphobiometric, physiological and biochemical indices of the needles are closely connected with the state of the forest stand itself. It is then possible to contruct a respective model.

To describe the state of the forest on the basis of bioindicative parameters of needles was done in three stages: 1) analyzing the closeness of the relation between the studied parameters and state of the forest stand; 2) selecting a moderate number of informative signs which were sensitive and easily determinable in field conditions; and 3) calculating the regression equations that allow the prediction of the state of the forest stands on the basis of the determined bioindicative indices.

At the first stage, a correlation analysis was carried out which displayed a close relation between morphological, physiological, biochemical parameters of the needles and the state of the forest stands.

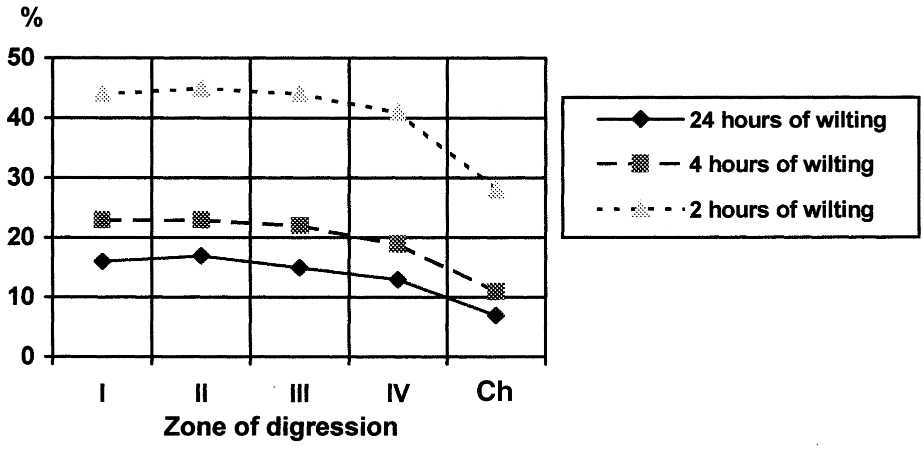

Figure 1. Rate of water loss by spruce needles within different zones of forest stands digression.

Categories of the sanitary state of forest stands especially closely related to contents of sulphurous anhydride in the air (0.95), sulphur in the needles (0.92), nickel in the needles (0.92), shoot length (0.95), number of needles at the shoot (0.96), percentage of water loss relative to dry weight (0.98), and weight of 100 dry needles (0.81). The content of sulphur dioxide in the air correlates with all of the signs being studied. An especially close relation was discovered with an average number of needles at the shoot (0.92), percentage of water loss (0.95). contents of nickel (0.97) and copper (0.92) in the needles. The least related indices within the system being studied turned out the following pair of signs: 3–8, 4–7, 8–10, 8–12, 10–12 (Table III).

At the second stage, a selection of needle parameters most susceptible to the changes in the concentration of pollutants was carried out. With that end in view, values of parameters were expressed as percentages in relation to maximum (along the gradient) concentration of sulphur dioxide in the air that varied from 0.28 mg/m^3 in the complete digression zone to 0.04 mg/m^3 at check plots. The range of relative parameter values is presented by the following histogram (Figure 2).

The paramemeters are arranged according to sensitivity decrease. It resulted that the most susceptible parameters were the contents of copper, nickel and sulphur in the needles, the water-holding capacity of the needles after wilting 2 and 4 h, as well as thw eight of 100 dry needles.

A selection of the informative signs, namely those least related with each other and containing information on the state of the forest stands was also performed. Within the framework of the method, the algorithm of V.A. Rozhkov (1989) coupled with the concentruction of a dendrogram was applied. The method consists of calculating the similarity between objects, i.e., the relative distance between them

TABLE III

Matrix of correlation coefficients for some indices of spruce stands

	1	2	3	4	5	6	7	8	9	10	11
2	0.57										
3	0.78	0.95									
4	0.35	0.92	0.77								
5	0.43	0.95	0.89	0.83							
6	0.53	0.96	0.92	0.84	0.98						
7	0.33	0.84	0.67	0.55	0.96	0.91					
8	0.48	0.81	0.62	0.89	0.79	0.89	0.67				
9	0.54	0.90	0.95	0.85	0.90	0.97	0.93	0.74			
10	0.24	0.84	0.77	0.73	0.94	0.84	0.95	0.53	0.92		
11	0.40	0.88	0.73	0.92	0.79	0.74	0.65	0.67	0.84	0.79	
12	0.83	0.92	0.97	0.79	0.79	0.84	0.66	0.57	0.88	0.57	0.83

Note 1 – class of tree growth (according to Kraft), 2 – category of sanitary state, 3 – concentration of SO_2 in the air, 4 – content of sulphur in needles, 5 – shoot length, 6 – number of needles at the shoot, 7 – weight of 100 wet needles, 8 – weight of 100 dry needles, 9 – water content of 5-yr-old needles, 10 – rate of water loss after wilting 5 h, 11 – electriconductivity, 12 – content of nickel in needles.

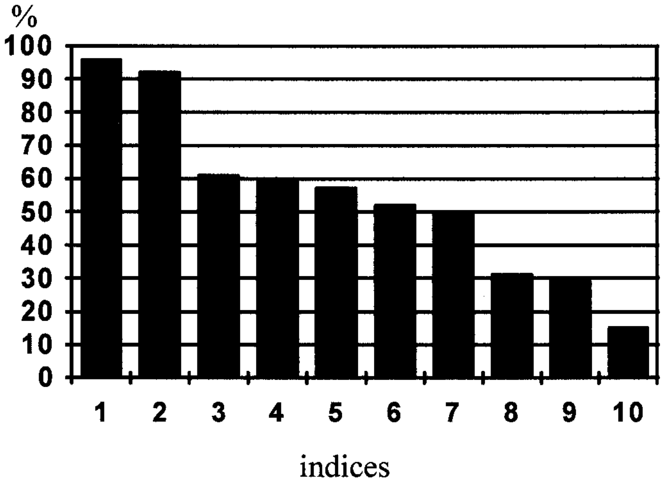

Figure 2. The spruce needles indices changeability depending on the concentration of pollutants. Were, 1 – Cu in needles; 2 – Ni in needles; 3 – water-holding capacity of needles (WHC) (after wilting 2-h); 4 – S in needles; 5 – WHC (after 4 h); 6 – weight of 100 completely dry needles; 7 – water content of 5-yr old needles; 8 – weight of 100 wet needles; 9 – WHC (after 24 h); 10 – water content of 1-yr-old needles.

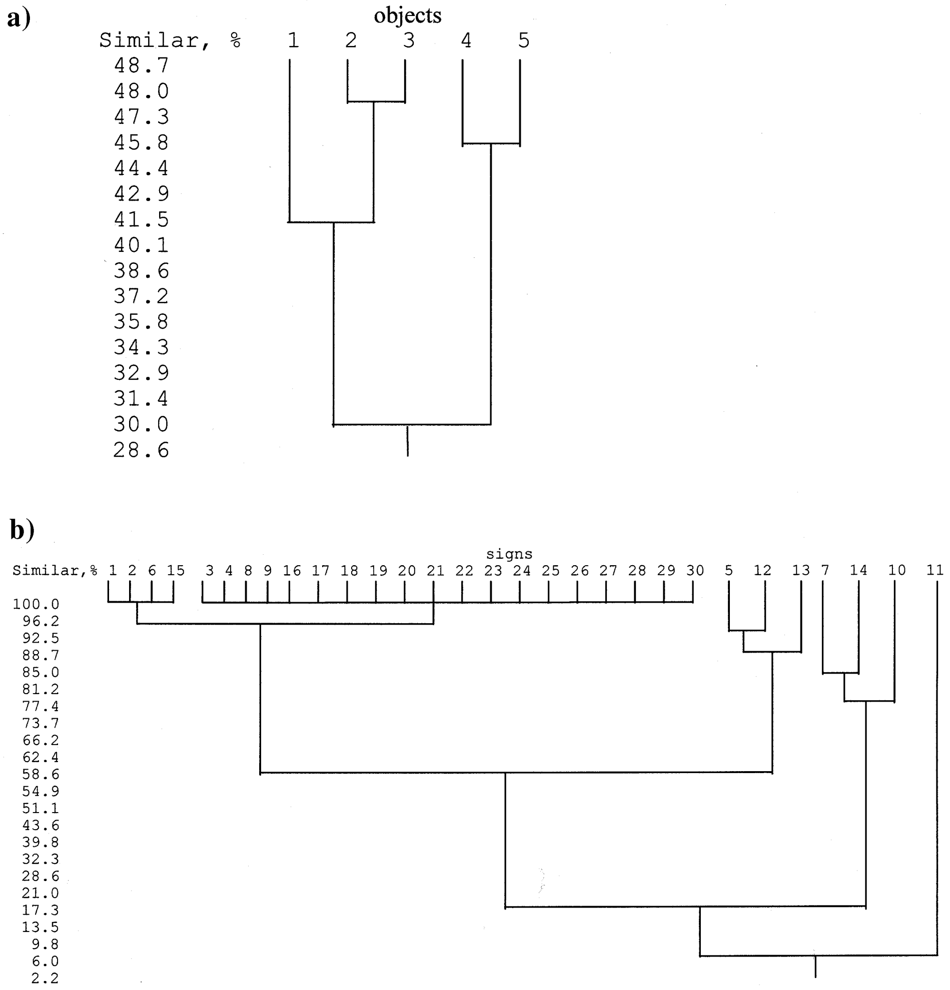

Figure 3. a) The similarity between objects in the 30-dimensional space of signs. 1..5 - digression zones. b) The similarity between signs in the 5-dimensional space of objects.

in the n-dimensional space of signs (Figures 3a, 4a) and similarity betweem signs in the 5-dimensional space of the objects (Figures 3b, 4b).

Figure 3a shows that the studied signs make it possible to discernzones of digression in a reliable way. However, Figure 3b shows that some of the signs are characerized by a high similarity, i.e., they duplicate one another and contain no additional information. Only one sign out of the group that are closely related could be retained. When eliminating signs at each stage, control over the reliable discerning of digression zones was carried out. This method made it possible to single out the most informative signs, namely the weight of 100 dry needles and the content of nickel in the needles.

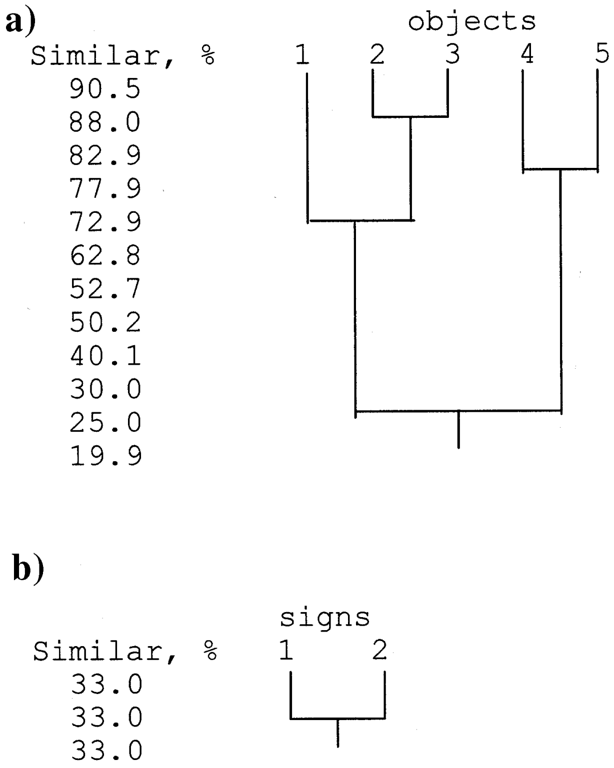

Figure 4. a) The similarity between objects in the 2-dimensional space of signs. b) The similarity between signs in the 5-dimensional space of objects.

4. Conclusions

During of course of analyzing all of the examined signs, we were able to single out parameters of the needles most suspectible to changes in the concentrations of pollutants and, at the same time, extract information with regard to the state of the forest stands by taking into account the closeness of reciprocal relation. The following indiceswere included into this group of parameters: morphological (weight of 100 dry needles), physiological (rate of water loss after wilting 4 h) and biochemical (content of pollutants, i.e., nickel, copper and sulphur in the needles) indices. We recommend usin these indices as being bioindicative. They make it possible to judge the changes in the vital functions of a tree species, in particular Norway spruce, at the early stages of any damage caused by industrial emissions, i.e., before changes become visible.

A possibility of applying bioindicative parameters of spruce needles with the purpose of predicting the sanitary state and level of the forest stand digression influenced by industrial emissions caused by the smelter complex is shown for the example of multiple regression equations (Table IV).

TABLE IV

Application of bioindicative parameters of needles for predictions

Regression equations	Dispersion		Determination coefficient	Criterion of significance
	general	residual		
SSC = 6.705 + 8.230 × W100 n	1.10	0.37	0.70	3.11
SSC = 0.319 + 3.045 × W100 n + 0.039 × WL4 + 18.650 × Cni	13.60	0.27	0.98	38.92
SSC = 0.985 – 2.430 × W100 n + 0.024 × WL4 + 0.840 × CSs	1.10	0.07	0.95	16.31
SDL = 7.080 + 1.900 × W100 n – 0.060 × WL4 – 1.160 × CSs	2.14	0.13	0.95	16.12
SDL = –1.978 + 11.300 × W100 n	2.14	0.79	0.67	2.83

Were, SSC – Category of sanitary state of the stands; W100 n – Weight of 100 dry needles; WL4 – Rate of water loss after wilting 4 h; CNi – Content of nickel in needles; CSs – Accumulation of sulphur in the snow; SDL – Level of stand digression.

References

Karaban’, R. T. and Rudneva, N. A.: 1988, Accumulation of metals caused by technogenic factors in soils and arboreal vegetation. In: *Proceedings of the Institute of Applied Geophysics* **72**, 65–74. (In Russian).

Lyanguzova, I. V.: 1990, Accumulation of chemical elements by Scotch pine in the pine forest of Kola Peninsula. In: *Problems of forest science and forest ecology. Abstracts of reports*, 273–275. (In Russian).

Maslov, Yu. I.: 1978, Micros determination of sulphur in the plant material. In: *Methods of biochemical analysis of plans*, LGU, Leningrad, LGU, Leningrad: 146–154. (In Russian).

Rozhkov, V. A.: 1989, *Soil informatics*, Agropromizdat, Moscow, p. 221. (In Russian).

Smith, W. H.: 1985, *Forest and atmosphere*, Progress, Moscow, p. 429. (In Russian).