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On the Methods for Measuring Forest Litter Thickness to Diagnose the Technogenic Disturbances of Ecosystems

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Abstract—The thickness of forest litter on the test area (except zones around tree trunks) demonstrates a normal distribution and does not depend on the gradient of pollution from a copper-smelting plant. The most informative thickness indices are arithmetic mean and the upper quartile of a sample. To roughly divide the test area into the background and impact zones, seven to eight measurements are sufficient; to estimate arithmetic mean with an error of 0.5 cm, the number of measurements should be 6–57 for coniferous litter and 2–13 for leaf litter.

INTRODUCTION

The thickness of forest litter is an important parameter characterizing the intensity of destructive processes and reflecting the balance between input and decay of organic substances in the ecosystem. The litter immediately responds to chemical pollution (Armand *et al*., 1991; Chernen'kova, 1991), and its thickness increases near the point sources of discharges (Vorobeichik, 1995; Freedman and Hutchinson, 1980; Strojan, 1978; Tyler, 1984). This occurs mainly because of the inhibition of saprophilous complexes in the soil biota. Correlations between litter accumulation and concentrations of pollutants in it were revealed (Coughtrey *et al*., 1979); corresponding dose–effect dependencies (concentration–litter thickness) proved to be S-shaped (Vorobeichik, 1995). This is evidence that parameters of the litter may be successfully used to diagnose technogenic disturbances in forest ecosystems. However, some methodological problems have not been solved.

FORMULATION OF THE PROBLEM

Traditionally, litter thickness is measured when describing soil cuts. As only one value is considered, the accuracy of measurements is low, and conclusions completely depend on the researcher's intuition in determining the location of a cut. For this reason, specialists prefer another index, litter accumulation (Karpachevskii, 1981), although it is more difficult to measure. However, the proper measurement of litter thickness can make this index sufficiently objective, reliable, and accurate, with lesser expenditures of labor and time.

In this work, I analyzed changes in statistical parameters of litter thickness along the gradient of technogenic pollution to obtain the data necessary for developing a correct procedure of measurements.

EXPERIMENTAL

Region of Study

The research were carried out in the southern taiga subzone, on territory that has been exposed for more than 50 years to air pollution by the discharge from the Middle Ural Copper-smelting Plant (the town of Revda). The main components of discharge are SO_2 and heavy metals (Cu, Pb, Zn, Cd, etc.). Technogenic acidification of the environment (shift of pH_{water} in soil (0–5 cm) from 5.5–6.2 to 4.4–4.8) results in a high biogeochemical activity of metals and, thus, their toxicity for the biota. Concentrations of movable forms of Cu, Pb, and Cd in soils near the plant exceed the local background level more than 10 times. This creates a powerful gradient of load on the forest ecosystems, whose degradation is noticeable over a distance of up to 4–5 km from the plant. The data on the degree of pollution and technogenic changes in forest vegetation were described previously (Vorobeichik, 1995; Vorobeichik and Khantemirova, 1994; Vorobeichik *et al*., 1994). In this work, birch, fir, and pine woods on gray forest and brown mountain–forest soils were studied.

MATERIAL AND METHODS

Litter thickness measurements were carried out in July, 1990 in 85 test plots (25 × 25 m) located in the nodes of a regular rectangular lattice (5 × 17 km) with 1-km spacing. The study region extended in the direction opposite to that of prevailing winds. Here, the term *litter* refers to leaf and ferment horizons (L and F). Humus horizon (H) is not considered, because its boundary is often difficult to determine; the same concerns freshly fallen leaves. Litter thickness was measured with a ruler to an accuracy of 0.5 cm in 30 trenchlets per test plot. Litter–soil boundary was determined analyzing soil (litter) structure, density, and color. Trenchlets

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Table 1. Information value of different indices of litter thickness (*F*-ratio)

Parameter	Criterion of load		
	distance from the plant	metals in snow	metals in soil
Arithmetic mean	30.26	15.94	10.29
Geometric mean	29.29	15.27	9.79
Median	28.22	15.06	9.82
Mode	17.70	11.08	6.79
Minimum limit	19.90	11.03	6.70
Maximum limit	20.78	16.85	8.86
Range	8.90	10.27	6.65
Lower quartile	26.44	14.03	8.28
Upper quartile	28.93	15.78	11.20
Interquartile range	6.94	6.94	9.50
Asymmetry	1.12*	0.31*	0.32*
Excess	1.02*	0.43*	1.64*
Variation coefficient	5.21	1.82*	1.25*
Homogeneity index	1.37*	1.20*	1.70*
Deviation from normal distribution according to Kolmogorov test	2.83	1.46*	3.22

* Values are nonsigficant (at 5% level of significance).

were randomly distributed throughout the territory, except the areas near the trunks (up to 0.5–1.0 m in radius) and forest glades.

RESULTS AND DISCUSSION

Information Value of Indices

Litter thickness can be characterized by many specific indices, but this increases “informational noise” and interferes with correct diagnosis. An index can be included in the system of diagnostic traits only if it has sufficient information value. According to Armand *et al.* (1991), I regard the information value of the index as its variation in response to the load on a test system. The higher the variation (data scattering) at different loads and the less the data scattering at the some load, the higher the information value. Hence, it is logical to measure the information value by means of Fisher’s *F*-test used in conventional analysis of variance (the ratio of intergroup variance of means to the mean of intergroup values of variance).

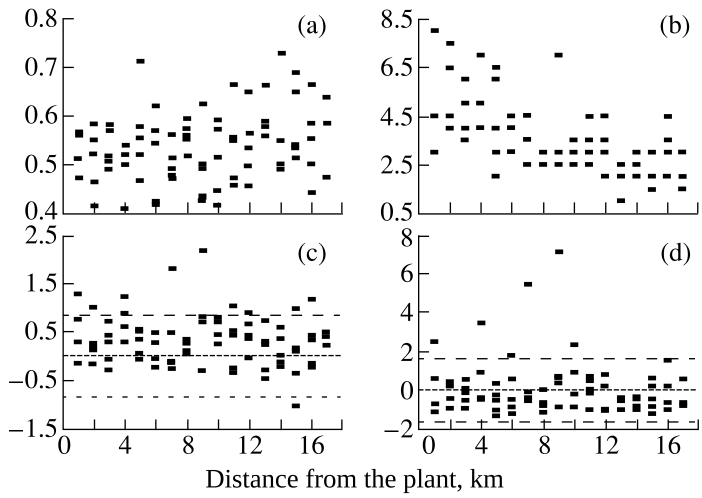
Information values of indices characterizing litter thickness in different ways differ significantly (Table 1). This is evidence for the necessity of comparing the parameters before including them into the system of diagnostic traits. The series of information values also differ if different approaches are used to estimate the doze of technogenic load. We used three criteria: the distance from the source of discharges, gross content of Cu, Pb, and Cd in snow, and the content of movable forms of the same elements in the upper soil level (0–5 cm). In the last two variants, the cumulative pollution index (the sum of differences between the actual and background concentrations) was used. Differences between results are likely to reflect statistical (rather than functional) relationships between the above approaches to the estimation of load, which characterize the level of technogenic impact on ecosystems from different aspects.

Thus, it is necessary to chose indices that remain highly informative whatever approach is used to estimate the load. There are two of them: arithmetic mean and the upper quartile of sample, and they can be successfully used to diagnose forest ecosystems. The maximum sample limit, being highly informative in one variant of load measurements, has low information value in other variants. This is probably associated with the sensitivity of ordinal statistics to accidental deviations.

Other analytical means (geometric), mean positions (median, mode, and lower quartile), and minimum sample limit are significantly less informative. Parameters of variability (ordinary and interquartile range, variation coefficient, and homogeneity index) and statistical distribution (asymmetry and excess) are also poorly informative, because they demonstrate no variation with respect to the pollution gradient (figure).

Variation in Thickness

The basis for developing a correct procedure for measuring litter thickness is the data on variability of this parameter (see figure and Table 2). Accuracy in estimating thickness (error–mean ratio) is quite high: 3.4–9.8% in the background territory and 3.2–7.6% in the impact zone (on average 5.7%). The range of variation in thickness increases as we approach the source of



Change in spatial distribution of litter thickness as a function of the distance from the plant: (a) homogeneity index, (b) variation of values (cm), (c) asymmetry, (d) excess. Dotted line shows the level beyond which asymmetry and excess significantly differ from zero ($p < 0.05$).

discharge, reaching 7–8 cm (vs. 1.5–4.5 cm in the background territory). It is associated with the fact that the areas with litter thinned due to degradation of herb–dwarf shrub layer are being formed within the impact territory. An increase in variation means that the values of litter thickness are distributed within broader limits.

Spatial heterogeneity was estimated using the homogeneity index proposed earlier, i.e., the ratio of observed dispersion (variance) to that maximum possible under the fixed limits (Vorobeichik, 1986):

$$K = \sqrt{\frac{D}{(X_{max} - X_{av})(X_{av} - X_{min})}},$$

where D is dispersion and X_{max}, X_{av}, and X_{min} are the maximum, average, and minimum values in a sample. This index levels off the influence of sample limits and gives the “true” component of variation, being zero at minimum heterogeneity and one at maximum heterogeneity. Homogeneity index for some areas of the background territory was increased (above 0.6), probably because litter thickness was close to the limit of accuracy of measurements (0.5 cm). In other cases, the index remained stable throughout the gradient of load (0.4–0.6), providing evidence for random (uniform) spatial distribution of litter, without local thinning. Thus, the technogenic load widens the limits of thickness, but the level of variability within them remains

Table 2. Average litter thickness, parameters of its variability, and sample size necessary for estimating the mean with admissible error of 0.5 cm at 5% level of significance

Parameter	Litter composition and zone of load			
	leaf		coniferous	
	impact (3)	background (27)	impact (21)	background (34)
$\bar{X}$, cm	4.2	1.9 (0.7–2.9)	5.4 (4.7–6.6)	2.3 (1.5–3.4)
s, cm:				
within the plot	0.78	0.69 (0.28–0.93)	1.34 (1.00–1.93)	0.88 (0.65–1.31)
between plots	0.11	0.52	0.57	0.42
CV, %:				
within the plot	18.6	36.6 (25.1–54.0)	25.0 (17.4–41.3)	38.2 (28.1–52.9)
between plots	2.5	26.6	10.6	18.6
Sample size:				
samples per plot	9	7 (2–13)	28 (15–57)	12 (6–26)
plots per zone	1	4	5	3

Note: $\bar{X}$ is arithmetic mean, *s* is standard deviation, *CV* is variation coefficient; the number of examined test plots is shown in parentheses.

constant. The “true” component of variation coefficient is masked under the effect of wider limits; hence, differences between impacts zones arise.

The statistical distribution of thickness corresponded to the normal law throughout the pollution gradient. Only 3.5% of test plots demonstrated significant deviation from normal distribution (Kolmogorov–Smirnov test, $P < 0.05$). For 10.6% of plots, $0.05 < P < 0.10$ (normal distribution less apparent). Asymmetry and excess were constant throughout the pollution gradient, approaching zero in 87–93% test plots, which is also characteristic for normal distribution. In all other cases, except one, there is a positive deviation of asymmetry and excess, resulting probably from an increased proportion of small values obtained during measurements (see above).

Our data contradict the conclusion (Karpachevskii, 1981) that forest litter accumulation (which is analogous to litter thickness) does not correspond to normal distribution. This is the result of differences in the scheme of measurements: Karpachevskii made a series of tests moving from one tree trunk to another. Hence, the distribution was polymodal, with one frequency peak corresponding to the areas around trunks (up to 0.5–2.5 m in diameter), and another peak corresponding to the area between the trunks. In the present study, the first peak is initially excluded, and distribution is unimodal. This difference in methods is responsible for significant divergence in variation coefficients: the values obtained by Karpachevskii are more than two times higher (53–68%). Coefficients calculated for the areas separately near the trunks and between them are similar to those obtained in this work (14–16%). Moreover, similar ranges of variation in litter thickness were observed in north-taiga spruce forests (18–55%; Kashulina, 1990) and oak forests (20–29%; Strojan, 1978).

Sample Size

Necessary sample size depends on the parameters of spatial heterogeneity. The analysis of pollution-induced changes in litter thickness (Vorobeichik, 1995) allowed me to distinguish two different zones: background and impact. The buffer zone is small and includes the areas with litter thickness common for both background and impact zones. Mean-square deviations and means differ from one zone to another. Hence, necessary sample sizes calculated from the standard formula (Zaitsev, 1984) differ as well (Table 2): sample size should be greater for coniferous litters, compared to leaf litters, and for the impact zone, compared to the background zone. Variation of means within a zone is much lower than within a test plot. Therefore, the number of test plots necessary to estimate the mean thickness in the zone is small, three to five (the data on leaf litters in the impact zone are unreliable, because only few test plots were examined).

Sample sizes calculated in this way allow the estimation of mean thickness with an admissible error of 0.5 cm (corresponding to accuracy of 10–20%) at 5% level of significance. Another problem, more important for diagnosis, is whether to accept or reject the hypothesis that a given test plot belongs to the background zone. The sample size necessary for this purpose can be determined from the formula (Aivazyan *et al*., 1983):

$$n = \frac{(u_{1-\alpha} + u_{1-\beta})^2}{R(H_0, H_1)},$$

where u_q is quartile of q level for the standard normal law, α and β are probabilities of errors of the first and second type (to reject the null hypothesis if it is correct; to accept the null hypothesis if the alternative one is correct); R is the “distance” between the null (H_0) and alternative (H_1) hypotheses (calculated as integral of the difference of distribution densities for the null and alternative hypotheses). This method of calculation is used in the STATGRAPHICS software package.

In our case, the null hypothesis is that the test plot belongs to the background zone, and the alternative hypothesis is that it belongs to the impact zone. During calculations, we assumed that $\alpha = \beta = 0.05$. The following result was obtained: in the worst case (the highest mean in the background zone, the lowest mean in the impact zone, and maximal variance), the necessary sample size is 7 measurements for leaf litter and 8 for coniferous litter. It is interesting that, in the best case (the lowest mean in the background zone, the highest mean in the impact zone, minimal variance), only one measurement is needed for both coniferous and leaf litters. Hence, a minimal number of measurements is required to subdivide the territory into two zones sharply differing in litter thickness.

CONCLUSION

It was shown (Vorobeichik, 1995) that litter thickness is an adequate parameter to diagnose the disturbances of ecosystems. Its use in correctly chosen test plots provides the possibility of reliably dividing territory into zones with respect to the intensity of destructive processes. This work showed that litter thickness is an accurate index allowing specialists to obtain important data after only a few measurements. To divide a territory roughly into the background and impacts zones, only 7–8 measurements are necessary. To estimate the mean in the background territory (with acceptable accuracy), 6–26 measurements are necessary for coniferous litter, and 2–13 measurements, for leaf litter. In the impact territory, 15–57 and 9 measurements should be made, respectively. This method is less labor- and time-consuming than analysis of litter accumulation. Hence, litter thickness can be included in the system of diagnostic traits for evaluating the state of forest ecosystems (express estimation). Statistically, arithmetic mean is the most informative index, and the upper quartile of the sample can be used as an additional index.

Spatial variation in parameters of litter depends primarily on a parceled structure of biogeocenoses (Karpachevskii, 1981; Baranova, 1988). Hence, the advantages of litter thickness as an index manifest themselves when a usual scheme of randomized sampling is limited, i.e., stratified sampling is used): three territorial types are distinguished (areas near trunks, between trunks, and openings), and litter thickness is estimated for every type separately. Mixing the types in one sample leads to a sharp increase in variation and, hence, to erroneous conclusions. During field measurements, this aspect is even more important than correct sample size.

REFERENCES

Aivazyan, S.A., Enyukov, I.S., and Meshalkin, L.D., *Prikladnaya statistika: Osnovy modelirovaniya i pervichnaya obrabotka dannykh* (Applied Statistics: Principles of Modeling and Initial Data Processing), Moscow: Finansy i Statistika, 1983.

Armand, A.D., Kaidakova, V.V, Kushnaryova, G.V., and Dobrodeev, V.G., Determining the Limits of Stability for Geosystems in the Vicinity of the Monchegorsk Combined Metal Works, *Izv. Akad. Nauk SSSR, Ser. Geogr.*, 1991, no. 1, pp. 93–104.

Baranova, T.A., Use of the Transect Method in Studies on Forest Litter Reserves, in *Problemy ekologii Pribaikal'ya* (Ecological Problems of the Baikal Region), Irkutsk, 1988, p. 4.

Chernen'kova, T.V., Phytoindication of Early Stages of Technogenic Disturbance in the North Taiga Biocenoses, in *Bioindikatsiya i biomonitoring* (Bioindication and Biomonitoring), Moscow, 1991, pp. 114–120.

Coughtrey, P.J., Jones, C.H., Martin, M.H., and Shales, S.W., Litter Accumulation in Woodlands Contaminated by Pb, Zn, Cd, and Cu, *Oecologia* (Berlin), 1979, vol. 39, no. 1, pp. 51–60.

Freedman, B. and Hutchinson, T.C., Smelter Pollution near Sudbury, Ontario, Canada, and Effects of Forest Litter Decomposition, in *Effects of Acid Precipitation on Terrestrial Ecosystems*, New York, 1980, pp. 395–434.

Karpachevskii, L.O., *Les i lesnye travy* (Forest and Forest Herbs), Moscow: Lesnaya Promyshlennost', 1981.

Kashulina, G.M., Some Features of Intrabiogeocenotic Differences in Properties of Al–Fe–Humic Podzols, in *Struktura i funktsii nazemnykh i vodnykh ekosistem Severa v usloviyakh antropogennogo vozdeistviya* (Structure and Functions of Terrestrial and Aquatic Ecosystems of the North under Anthropogenic Influence), 1990, pp. 71–84.

Strojan, C.L., Forest Leaf Litter Decomposition in the Vicinity of a Zinc Smelter, *Oecologia* (Berlin), 1978, vol. 32, no. 2, pp. 203–212.

Tyler, G., The Impact of Heavy Metal Pollution on Forest: A Case Study of Gusum, Sweden, *Ambio*, 1984, vol. 13, no. 1, pp. 18–24.

Vorobeichik, E.L., Qualitative Indices of Spatial Structure in Biogeocenosis Research on Terrestrial Ecosystems, *Ekologiya*, 1986, no. 2, pp. 94.

Vorobeichik, E.L., Changes in Forest Litter Thickness under Chemical Pollution, *Ekologiya*, 1995, no. 4, pp. 278–284.

Vorobeichik, E.L., Sadykov, O.F., and Farafontov, M.G., *Ekologicheskoe normirovaniye tekhnogennykh zagryaznenii nazemnykh ekosistem (lokal'nyi uroven')* (Ecological Standards for Technogenic Pollution of Terrestrial Ecosystems (Local Level)), Yekaterinburg: Nauka, 1994.

Vorobeichik, E.L. and Khantemirova, E.V., Response of Forest Phytocenoses to Technogenic Pollution: Doze–Effect Relationships, *Ekologiya*, 1994, no. 3, pp. 31–43.

Zaitsev, G.N., *Matematicheskaya statistika v eksperimental'noi botanike* (Mathematical Statistics in Experimental Botany), Moscow: Nauka, 1984.