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METHODOLOGY OF SOIL MONITORING IN A FORESTED ZONE OF THE KARKONOSZE NATIONAL PARK WITH REFERENCE TO THE DIVERSITY OF SOIL PROPERTIES

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Abstract. This paper presents the introductory considerations for soil monitoring to be established in the forested zone of the Karkonosze National Park. The strategy and techniques of soil sampling are discussed with reference to the variability of soil properties. Based on the examples of 12 monitoring areas and the detailed analysis made for 5 of them, it was found that particularly high spatial differentiation (with SD> 50%) was typical for several soil parameters, i.e. the thickness of organic horizon, concentrations of available nutrients and total concentrations of heavy metals. On the contrary, the soil pH reaction did not vary significantly. Calculated total pools of nutrients and pollutants present in soil organic layers were comparable with those accumulated in mineral soil horizons to a depth of 20 cm. The data proved that such parameters as mean thickness of organic layer, surface coverage with rocks and the contribution of skeletal fractions in the mineral soil are of great importance for correct estimation of soil quality, in particular for the correct assessment of nutrient supply and the amount of pollutants accumulated in soils.

The need to establish regular systems of environmental monitoring, especially for the most susceptible ecosystems, has been recognised and has become an important task over the past two decades. Polish State Monitoring of the Environment was established in 1992 [16], focussing mainly on urban and industrial sites, as well as agricultural lands. A specific soil-monitoring programme for various natural ecosystems has not been developed, however, an Integrated Monitoring net was planned to register the changes in various ecosystem compartments at selected sites [8, 10]. The Special European framework for soil management and protection, entitled 'Towards a Thematic Strategy for Soil Protection', has been developed at the European Commission

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level [2]. It became unquestionable that soil properties play a crucial role in controlling the sustainability of ecosystems, in particular those exposed to unfavourable environmental conditions or anthropogenic pressure. In this respect, special attention should be given to the areas protected by law, such as national parks or natural preserves. Polish legislation requires that all national parks establish special systems for environmental monitoring [16].

Karkonosze National Park experienced a tremendous ecological disaster when its forests declined in the 1980s and 1990s, and therefore has been one of the first Polish national parks to establish a regular and comprehensive monitoring system. This system consists of 630 circular areas in the forested zone and a further 230 areas in the subalpine zone, both arranged on a 200x300 m grid, as well as 10 other areas for special permanent monitoring [5]. Figure 1 illustrates the spatial distribution of circular monitoring areas throughout the entire National Park. It should be pointed out that a large number of circular monitoring sites can supply exceptionally detailed information on the environmental properties in the park. The need to establish such a dense net of monitoring sites was determined by the high spatial diversity of habitats present in the National Park, as well as by the necessity to control even slight changes in the monitored parameters that might affect the delicate equilibrium in a fragile ecosystem [12]. For comparison, Montanarella and Negre [13] estimated that for the Alpine Soil Information System, during the systematic survey phase carried out on the scale 1:250 000, the realistic amount of observations needed at high variability should be one observation per 1 km^2; while at low variability this should be one observation per 6 km^2.

Fig. 1. Distribution of circular monitoring areas within the Karkonosze National Park. Darker spots are monitoring sites in the forested zone of the Park, while lighter spots are those in the sub-alpine zone.

In this paper, we present some introductory considerations focusing on a planned methodology of soil monitoring, which will be an integral part of the monitoring of habitats in the forested zone of the National Park.

Soil sampling does not need to be repeated more often than once every 5 years [7]. The choice of soil properties to be examined has been based on the assumption that they should be easily measured and that it is essential to assess soil quality with respect to natural soil function and user oriented functions [14]. Once soil features suitable to serve as indicators of soil quality have been selected, it is important to ensure that suitable methods of sampling, pre-treatment and analysis are selected, appropriate for this evaluation. It is also important that soil sampling and analysis procedures allow the detection of presumed changes from the starting values with a certain degree of confidence. Many authors point out that due to high soil variability, detecting measurable changes in soil properties with a high level of confidence requires a large numbers of replicates. Spatial variability is one of soil's immanent features, particularly strongly expressed in forest soils and mountain soils [1, 9, 20]. Interactions between tree roots and bulk soils, as well as between forest canopy and air-borne depositions, play a crucial role in creating soil variability [3, 11]. Therefore, some authors suggest that it will be practically impossible to detect changes as low as 10% from the mean value of a soil property with high confidence (90%), however detecting a 25% change from the median would not be a problem [20].

The main aim of this study was to discuss the strategy and technique of soil sampling as well as to estimate the variability of soil properties in the forested zone of the National Park with the aim of establishing the most appropriate methodology for soil monitoring.

METHODS

From among 630 monitoring areas (Fig. 1), twelve were chosen for this study. They represented various forest habitats and different soil types, and were situated at various altitudes: from 630 to 1220 m. The variability of soil properties was measured within these areas. To achieve this, soil samples were collected in 4 replicates - from 4 sites located within a circular monitoring area at different parts (west, north, east and south) of its outer zone (Fig. 2). Each of those replicates was obtained by mixing soil material collected from 3 or 4 points within an area 2 m in diameter. A detailed description of the sampling technique is important for the right interpretation of laboratory results [21]. Additionally, in each area we thoroughly described the data characterising the micro-relief of the site, including slope incline and the proportion of the surface covered by stones and rocks.

Sampling depth was based on the presumption that the most important pool of plant available nutrients and pollutants is concentrated in the surface soil layers.

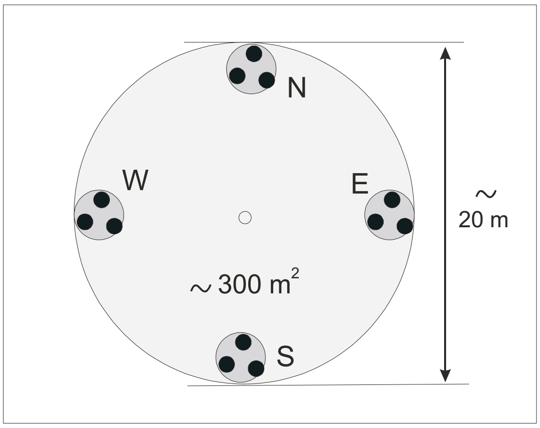

Fig. 2. Detailed location of soil sampling sites within one circular monitoring area. Black spots indicate the separate sub-sampling sites, representative for a 300 m^2 monitoring area.

Possible changes in soil properties will also be best detectable in the surface soil layers. Moreover, deep soil sampling would not be technically possible because of the dramatically increasing contribution of skeletal fractions (gravel and stones) with soil depth. Therefore, soil samples were taken from the following depths:

– mineral soil: 0-10 and 10-20 cm;
– soil litter: the whole layer (with the depth measured and reported).

Twelve soil samples from mineral horizons, and further 12 samples of forest litter were collected from each monitoring site, and represented an area of 300 m^2. Several important soil features, such as the type of humus layer and the morphological properties of the mineral horizons were described in the field.

Organic soils were treated separately, and soil samples were collected from their layers (0-10, 10-20 cm), as well as from the mineral sub-soil if it was present within the depth of 50 cm. In order to minimize mechanical damage to the soil surface within the monitoring area, we used standardised soil sampling equipment, i.e. corers and split-tube samplers, for sample collecting, although some difficulties were found with distinguishing between soil litter and humic horizon. This may affect the results of determined soil properties and element concentrations in organic *vs.* mineral soil horizons, having however no further effects on the calculated pool of nutrients or pollutants as referred to the standardised area of 1 m^2 or 1 ha (see below).

Soil properties to be determined were those most important for soil fertility. Physical properties that sometimes may be crucial for monitoring [17] were not measured, as in the forested zone of Karkonosze National Park the problems related to an inefficient water supply does not occur because of the high yearly precipitation and good water holding capacity of the soils. It is mainly chemical properties that may negatively influence plant growth and ecological equilibrium [4, 6, 18]. In particular, the Karkonosze Mts. have been for many years exposed to immission and accumulation of air-borne pollutants, including sulphur and nitrogen oxides as well as heavy metals [6]. Acid rains caused a strong decrease in soil pH, as well as nutrient deficiency and are believed to be crucial factors of forest decline [4, 5, 22]. It has been shown for the Austrian Alps that despite a strong reduction of emissions in Europe, pollutants are still a potential stress factor, especially for sensitive mountain forest ecosystems [19].

Soil samples collected from the field, dried and then homogenised prior to analyses. The following soil properties were determined in the laboratory: grain size distribution, organic matter content, soil reaction pH in 1 mol dm^{-3} KCl, available nutrients (P_2O_5, K_2O and MgO), total concentrations of heavy metals: Pb, Cu, Zn and Cd, total sulphur and sulphates. Some of those properties, i.e. soil pH, available P, and total concentrations of Pb, Cu and Zn will be further discussed in detail. Representative data from 5 sites are presented in the tables, whereas comments concerning the other data are made in the text.

It should be stressed that it is the total pool of nutrients rather than their concentrations that determine the conditions for plant growth in ecosystems [15]. The pool of nutrients and pollutants M (g) accumulated in soil within the surface S (m^2) was therefore calculated as:

$$M\ (g) = C\ (g\ kg^{-1})\ \ S\ (m^2)\ d\ (m)\ \sigma\ (kg\ m^{-3}),\ \text{ or:}$$
$$M\ (g) = C\ (mg\ kg^{-1})\ S\ (m^2)\ d\ (cm)\ \sigma\ (g\ cm^{-3})\ /\ 100,$$

M – mass (pool) of component, C – concentration, S – surface, d – depth of layer, σ – soil bulk density.

For a rough estimation, soil bulk density was assessed as $\sigma = 0.2$ g cm^{-3} for organic horizons, 1.2 g cm^{-3} for humus horizons (or layer 0-10 cm) and 1.3 g cm^{-3} for deeper mineral horizons. The data were further improved by taking into account the estimated coverage of soil surface with rock fragments and stones. For each monitoring area examined in the study, the local variability of soil properties was estimated by a calculated standard deviation SD value, expressed in absolute values as well as in percent for the calculated mean value.

RESULTS

The most pronounced feature of the soils described in the field was a strong differentiation of micro-relief within one monitoring area, caused by the not rare occurrence of the spatial domination of rock fragments on the soil surface (Table 1) and in the soil profiles. This fact resulted in a great variability in the depth of weathered mineral material and organic layer. The depth of soil litter layer on the surface of mineral soils varied widely, so that the value of SD for this feature was

TABLE 1. SITUATION AND DEPICTION OF FIVE MONITORING SITES SELECTED FOR DETAILED ANALYSIS

Site No.	Habitat type	Dominant species	Soil type*	Altitude m	Surface coverage by rocks (%)	Depth of organic horizon			
						range	mean (cm)	SD (cm)	SD (%)
114/88	Sub-Atlantic pine forest	pine	Podzol	630	20	1-9	4.1	2.5	60.3
105/86	Mountain spruce-fir forest	spruce	Dystric Cambisol	680	15-40 (30)	1-8	3.3	2.0	59.2
114/76	Acidophilous mountain beech forest	beech	Dystric Cambisol	720	20-30 (25)	1-7	4.1	1.7	41.8
108/56	High-mountain Sudetic spruce forest	spruce	Hyperskeleti-Histic Leptosol	1160	> 50 (60)	5-22	10.5	6.0	57.0
114/48	High-mountain Sudetic spruce forest	spruce	Skeleti-Histic Regosol	1220	0	20-35	22.2	4.2	19.1

*Soil type - determined on the basis of the existing soil map, verified in the field.

high and ranged from 41.8 to 60.3% of the mean value (Table 1). It should be stressed that the proper estimation of a mean depth of organic horizon is of a crucial importance for calculating the pool of elements (both nutrients and pollutants) present in the organic layer on a given surface. This has particular consequences, as the results obtained from this study and the data from the literature [6, 18] proved that the concentrations of available nutrients and metallic pollutants (as expressed in mg kg^{-1}) are much higher in the organic horizons than in the mineral soil layers (Tables 2, 3).

TABLE 2. SOIL REACTION AND PHYTOAVAILABLE P IN SOILS AT FIVE MONITORING SITES SELECTED FOR DETAILED ANALYSIS

Site No.	Sampling depth (cm)	pH				P_2O_5			
		range	mean	SD	SD (%)	range	mean	SD	SD (%)
						(mg kg^{-1} d.m.)			
114/88	O*	3.0-3.9	3.3	0.4	11.3	86-199	142	48	33.7
	0-10	3.0-3.4	3.2	0.2	4.9	6-16	9	5	52.1
	10-20	3.7-4.1	3.8	0.2	5.0	<6	<6	0	0.0
105/86	O*	3.0-3.4	3.2	0.2	4.9	70-250	145	77	53.1
	0-10	3.2-3.7	3.4	0.2	6.6	6-7	6	0	8.0
	10-20	3.9-4.1	4.1	0.1	2.1	<6	<6	0	0.0
114/76	O*	3.0-3.2	3.2	0.1	2.7	92-189	128	44	34.5
	0-10	3.0-3.9	3.3	0.3	10.3	<6-6	6	0	0.0
	10-20	3.8-4.1	4.0	0.1	2.8	<6	<6	0	0.0
108/56	O*	3.0-3.7	3.4	0.3	7.7	58-92	69	16	22.5
	0-10	3.4-3.5	3.5	0.0	1.2	7-11	9	2	22.2
	10-20	3.2-3.6	3.4	0.2	4.8	6-9	7	1	20.2
114/48	O* (0-10)	3.0-3.4	3.2	0.2	5.6	7-62	38	23	61.7
	O* (10-20)	3.1-3.7	3.5	0.2	6.3	6-47	25	18	71.9

*O – organic horizons (forest litter or peat horizon).

The high level of soil coverage with stones and rock fragments is another factor to be taken into account in the interpretation of laboratory results concerning nutrients and pollutants. As the percentage of soil surface covered by the rocks of various diameters may locally exceed 50 % (e.g. site No. 108/56), then this leads to

TABLE 3. TOTAL CONCENTRATIONS OF Pb, Cu, AND Zn IN SOILS AT FIVE MONITORING SITES SELECTED FOR DETAILED ANALYSIS

Site No.	Sampling depth (cm)	Pb				Cu				Zn			
		range	mean	SD	SD (%)	range	mean	SD	SD (%)	range	mean	SD	SD (%)
		(mg kg^{-1} d.m.)				(mg kg^{-1} d.m.)				(mg kg^{-1} d.m.)			
114/88	O*	82.0-126	105	18.4	17.5	11.0-19.0	16.5	3.7	22.4	52.0-61.0	57.5	3.8	6.7
	0-10	43.5-69.5	54.3	11.5	21.3	5.0-7.0	6.1	0.9	15.7	22.0-24.0	23.0	1.2	5.0
	10-20	25.0-45.5	36.6	9.8	26.8	4.5-5.5	4.8	0.5	9.8	21.0-33.0	25.7	5.3	20.5
105/86	O*	41.5-119	95.7	36.4	37.9	12.0-18.0	14.7	2.7	18.7	45.0-58.0	51.0	5.8	11.5
	0-10	28.0-72.0	48.0	19.3	40.1	6.0-9.0	7.2	1.3	18.3	26.0-49.0	34.4	10.1	29.4
	10-20	23.5-45.5	37.7	9.7	25.8	5.0-9.0	6.5	1.7	26.6	29.0-59.0	41.0	13.9	34.0
114/76	O*	115-138	127	9.7	7.7	18.0-24.0	21.3	2.8	13.0	45.0-63.0	53.0	7.6	14.4
	0-10	54.0-78.0	64.7	10.0	15.4	6.5-9.5	7.8	1.3	15.9	30.0-45.0	36.9	6.9	18.6
	10-20	23.0-44.5	31.5	11.4	36.3	6.0-8.5	7.2	1.3	17.6	28.0-51.0	42.0	12.6	30.0
108/56	O*	148-200	178	25.5	14.4	14.0-22.0	18.6	3.8	20.5	51.0-92.0	64.3	18.9	29.4
	0-10	18.5-40.0	26.3	9.5	36.0	2.5-5.0	3.4	1.1	32.8	11.0-12.0	11.6	0.8	6.5
	10-20	20.5-31.5	24.8	5.9	23.6	2.5-3.0	2.7	0.3	9.8	12.0-17.0	14.5	2.5	17.2
114/48	O* (0-10)	120-248	197	57.5	29.2	8.0-27.0	19.7	8.5	43.2	32.0-42.0	38.3	4.3	11.4
	O* (10-20)	43.0-236	112	88.6	78.7	5.5-15.0	9.1	4.4	48.3	13.0-23.0	17.5	4.2	24.0

*O – organic horizons (forest litter or peat horizon).

considerable reductions in the amount of the earthy fraction present in the surface layers within a certain area, proportionally decreasing the total pool of elements present in the soil. Table 4 shows the data illustrating estimated pools of selected elements (nutrients and pollutants) with and without considering the mean degree of surface coverage by stones (as assessed in Table 1). The photos (Figs 3, 4) show typical habitats and illustrate the coverage of soil surface with the rock fragments in the mountain spruce-fir forest and high-mountain spruce forest zones (sites 105/86 and 108/56).

Our results show that the spatial variability of soil pH was relatively low (Table 2). Soil pH values apparently depended on the layer, and were the lowest in the surface layers and the highest in the deeper mineral layer (10-20 cm). Its standard deviation determined for separate layers varied from 0.14 pH unit in the case of deeper mineral layer (10-20 cm) to 0.22 in the forest litter, and the relative standard deviation values calculated generally for all 12 sites examined were as low as 7% for organic layer, and 4% for deeper mineral layer. Therefore, any possible future changes in soil pH will probably be detected and statistically shown with a high level of confidence. To the contrary, high variability of mean values were characteristic for concentrations of available nutrients and pollutants, and referred both to the means calculated for all monitoring areas as well as to those found within the areas themselves.

Table 2 illustrates the variability of available phosphorus, and Table 3 that of total Pb, Cu and Zn. As mentioned above, there were striking differences between the concentrations of all elements in the organic and mineral horizons. Available P (expressed as P_2O_5) remaining in the mineral horizons were extremely low and did not exceed 11 mg kg^{-1}, whereas its concentrations in organic layers varied up to 250 mg kg^{-1} with a mean value of 104 mg kg^{-1}. Lead concentrations in mineral soil samples ranged from 20 to 78 mg kg^{-1} whereas those in the forest litter reached a value of 250 mg kg^{-1}. Similar relationships were observed for Cu and Zn. However, if considering a very low bulk density of soil organic layers, then the total pools of elements present in the layer of a forest floor and in mineral horizons to the depth of 20 cm are, in fact, comparable (Table 4). Therefore, possible incorrect estimation of the mean thickness of organic horizon in the monitoring area may be of slightly lower importance for the assessment of nutrient supply or pollutant load than would be an incorrect estimation of surface coverage by rocks or neglecting the presence of skeletal fractions in the bulk soil. Considering the latter two parameters should be considered obligatory when interpreting the data for nutrients and pollutants present in the soils of forested mountain areas.

TABLE 4. AVAILABLE P AND TOTAL Pb, Cu AND Zn IN SOILS AT FIVE MONITORING SITES SELECTED FOR DETAILED ANALYSIS - CONCENTRATIONS AND CUMULATIVE POOLS RELATED TO 1 ha, kg ha^{-1}

Site No.	Sampling depth (cm)	Pools calculated without considering the presence of rocks (kg ha^{-1})								Pools calculated considering the coverage of soil surface with rocks (kg ha^{-1})			
		P_2O_5		Pb		Cu		Zn		P_2O_5	Pb	Cu	Zn
114/88	O*	14.2		10.5		1.7		5.8					
	0-10	10.8	32.8	65.2	123	7.3	15.2	27.6	67	24.2	97	11.9	53
	10-20	7.8		47.6		6.2		33.4					
105/86	O*	17.4	32.4	11.5		1.8		6.1					
	0-10	7.2		57.6	118	8.6	18.9	41.3	101	17.2	79	12.6	69
	10-20	7.8		49.0		8.5		53.3					
114/76	O*	10.2		10.2		1.7		4.2					
	0-10	7.2	25.2	77.6	129	9.4	20.4	44.3	103	19.1	97	15.3	77
	10-20	7.8		41.0		9.4		54.6					
108/56	O*	13.8		35.6		3.7		12.9					
	0-10	10.8	33.7	31.6	99	4.1	11.3	13.9	46	13.8	41	4.6	18
	10-20	9.1		32.2		3.5		18.9					
114/48	O* (0-10)	7.6	12.6	39.4	62	3.9	5.8	7.7	11	12.6	62	5.8	11
	O* (10-20)	5.0		22.4		1.8		3.5					

Fig. 3. Site No. 105/86. Mountain spruce-fir forest. Surface coverage by rocks estimated as 15-40%.

Fig. 4. Site No. 108/56. High-mountain Sudetic spruce forest. Surface coverage by rocks estimated as over 50%. Rocks are partly covered by a thin organic layer overgrown by heather and blueberry shrubs.

CONCLUSIONS

1. Most properties of the soils in the Karkonosze National Park show high variability. Particularly high spatial differentiation was found for the thickness of organic horizon as well as concentrations of available nutrients and total amounts of Pb and other heavy metals, both within monitoring area and between different monitoring sites. The values of relative standard deviation for those properties often exceeded 50 percent.

2. The data obtained for single soil samples cannot be interpreted as fully representative for the site where the sample was collected.

3. Soil reaction does not vary significantly within the area examined in our study.

4. Organic horizons, if compared with mineral soil horizons, contain much higher concentrations of all elements examined, and indicate much higher variability as reflected by high values of standard deviation.

5. Total pools of nutrients and pollutants present in soil organic layers are comparable with those accumulated in mineral soil horizons to a depth of 20 cm.

6. Correct estimation of the following seems to be of great importance for the assessment of nutrient supply and the load of pollutants accumulated in soils: organic layer mean thickness, surface coverage with rocks and contribution of skeletal fractions in mineral soil.

7. Further research work will be required to estimate standard deviation values of basic soil properties, as typical for various types of habitats and most common features of site location and relief.

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METODOLOGIA MONITORINGU GLEB LEŚNYCH KARKONOSKIEGO PARKU NARODOWEGO W ŚWIETLE BADAŃ NAD PRZESTRZENNYM ZRÓŻNICOWANIEM WŁAŚCIWOŚCI TYCH GLEB

W artykule zaprezentowano wstępne rozważania dotyczące monitoringu gleby, planowanego w strefie leśnej Karkonoskiego Parku Narodowego. Założenia i technika pobierania prób glebowych zostały przedyskutowane w odniesieniu do zmienności właściwości gleby. Na podstawie 12 obszarów monitoringowych, a także szczegółowej analizy 5 spośród nich, stwierdzono, że szczególnie wysokie zróżnicowanie (SD>50%) było charakterystyczne dla kilku parametrów glebowych, takich jak: miąższość poziomu organicznego, stężenie dostępnych biogenów i całkowita zawartość metali ciężkich. Z drugiej strony, odczyn gleby nie zmieniał się w istotny sposób. Obliczone całkowite zasoby biogenów i polutantów obecnych w warstwach organicznych gleby były porównywalne z zasobami w mineralnych poziomach gleby do głębokości 20 cm. Badania udowodniły, że takie parametry jak średnia miąższość poziomu organicznego, pokrycie powierzchni skałami i udział frakcji szkieletowych w glebie mineralnej, mają duże znaczenie dla właściwego określenia jakości gleby, szczególnie dla prawidłowego oszacowania zasilania biogenami i ilości polutantów zakumulowanych w glebie.