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ORIGINAL RESEARCH ARTICLE

The use of the particle size distribution of soils in estimating quality of mountain forest sites

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Abstract. The physical and chemical properties of soil are the basic features that are used in the assessment of mountain sites. The aim of this study was to produce a simple key for classifying forest sites in mountain areas using soil particle size distribution. 200 plots (standard typological space) were selected for examination, most of which are typical of the Carpathians — being dominated by flysch rock. A few plots were located in the Sudety and Tatra Mountains, which have a different surface geology, mostly metamorphic rock and granite. The study proved that soil properties (reaction, base saturation, content of base cations, organie carbon and nitrogen) are helpful in distinguishing and assigning soilsto particular site types. The particle size distribution of forest mountain sites separated into different categories interms of productivity. These results can be used to improve the classification of forest mountain sites.

Key words: forest soil, particle size distribution, mountain forest sites

1. Introduction

The particle size distribution of a soil is closely related to the properties of the parent rock. It is one of the basic factors determining the growth conditions of the forests developing on that soil under certain climatic conditions. The abundance of rock weathering in, especially, highly transformed clay minerals affects sorption properties, nutrient availability to plants as well as the biological depth of the soils derived from them.

The particle size distribution of a soil is one of the characteristics to be determined on the main and auxiliary typological sites during forest inventory in the mountain regions (Instruction on Forest Management Planning (Instrukcja Urządzania Lasu, 2012)). At the same time, there is no instruction that could improve the interpretation of the results of soil analysis and their use for the assessment of the fertility and productivity of forest sites.

The aim of this study is to show the regularities observed in the particle size analysis of soils of the mountain sites of different fertility and productivity. The authors attempted to develop a simple tool to improve the process of diagnosing the types of forest sites in the mountain regions based on soil particle size distribution.

2. Materials and methods

Two hundred sample plots meeting the criteria of a model typological site, where the relationship between vegetation cover and soil is evident, were selected for the research. Most of the plots represented sites and soils typical of the Carpathians built of flysch rocks. Some of the plots were located in the Sudetes and Tatras on a different parent material, mainly metamorphic rocks and granites (Table 1).

The paper broadly describes soil subtypes, which form diverse sites and are the most difficult to diagnose. These soil subtypes, Hyperdystric Cambisols and Albic Cambisol, are described in detail taking into consideration their location.

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On the basis of the results, a simple tool (chart) was proposed to facilitate the process of diagnosing sites in respective montane sub-zones, taking into account soil subtypes and their selected properties. The tool applies to soils and sites prevailing in the mountains having the greatest impact on forest management in the mountain regions. The relationships presented in Table 2 do not apply to valuable soils and sites associated with local orography and water relations as well as to the out-of-zone soils such as Histic Gleysols, Histosols and Fluvisols.

The research method applied to sample plots was consistent with the method used in the soil-site studies. Deep soil pits (1.0–1.2 m) were dug in the central part of each plot. A mixed bulk sample was taken from the horizons of humus accumulation. Soil samples from deeper horizons were taken from the main pit. Stands were measured on each plot (with an area of 0.25 ha) and a list of herb layer species was made to diagnose the types of forest sites by stand and herb layer vegetation.

The collected samples were subjected to analysis for basic soil properties according to the methods used in soil studies (Ostrowska et al. 1991), specifically to determine:

– Particle-size of soils using Bouyuocos-Casagrande's areometric method modified by Prószyński, grouping the particles into classes according to the Classification of the Polish Society of Soil Science (2008).

– pH in H_2O and in 1M KCl by potentiometry, using the soil to solution ratio 1:5 in organic horizons and 1:2.5 in mineral horizons.

– Hydrolytic acidity (Y) and the sum of exchangeable base cations (Skp) by Kappen's method, being the basis for the calculation of soil sorption capacity (T) and degree of saturation of the sorption complex with base cations (V).

– Exchangeable acidity and the content of mobile aluminium by Sokołow's method.

– Organic carbon using Tiurin method

– Total nitrogen using the Kjeldahl method.

– Content of calcium, magnesium, potassium and sodium in the 1M CH_3COONH_4 extract with pH 7 using the ASA method, including the calculated sum of base cations.

The assignment of the plots to forest site types was done according to the classification system by Alexandrowicz (1972) using four site attributes (climatic conditions, soil conditions, stand characteristics and herb layer vegetation). The obtained research material was classified separately for each of the climatic-forest zones established by Alexandrowicz (1972) on the basis of stable soil properties, soil type and subtype, kind of bedrock and soil particle size distribution. The types and subtypes of soils were determined according to the criteria set in the Classification of Polish Forest Soils (2000). Along with the soil diagnosis, the type of forest sites was determined on the basis of stand characteristics. The comparison of both diagnoses allowed to ultimately determine the type of forest site, which was additionally confirmed by the identification of plant species in the herb layer.

Statistical analysis of the data was performed using Statistica 10. The nonparametric Tukey's HSD test was used to determine the level of significance of differences between the mean properties in the genetic horizons of soils forming different forest sites.

Table 1. The number of research plots in the different elevation zones in connections with soil subtype and parent material

Location	Mountain ranges	Number of research plots soil subtype (type of parental material)
Upper montane zone	Beskids	4 Bw (sandstones), 2 BRk (sandstones)
	Sudetes	2 Bw (granites)
	Tatras	5 Bw (granites), 5 Rp (limestones and dolomites)
Upper sub-zone of the lower montane zone	Beskids	12 BRb (sandstones), 15 BRk (sandstones)
	Sudetes	10 BRk, 6 BRb, 5Bw (granites and nutrient-poor gneisses), 4 BRwy (alkaline igneous rocks)
	Tatras	7 Bw, 5 BRk (granites), 5 Rbr (limestones and dolomites)
Lower sub-zone of the lower montane zone	Beskids	48 BRk, 22 BRb, 13 BRwy (sandstones and schists)
	Sudetes	8 BRwy, 2BRw, 2 BRs (sandstones), 6 BRwy, 2 BRw (alkaline igneous rocks)
	Tatras	3 PRbr, 3 BRw, 2 BRwy (sandstones and schists), 2Rbr (limestones and dolomites)

Notes: Bw – Haplic Podzol, BRb – Albic Cambisol, BRk – Hyperdystric Cambisol, BRwy – Epidystric Cambisol, BRw – Eutric Cambisol, BRs – Cambisol Humic Eutric, PRbr – Calcaric Cambisol Sceletic, Rbr – Cambic Rendzic, Rp – Mollic Rendzic

3. Results

The biggest problem in estimating the quality of mountain sites is the assessment of the productivity of Hyperdystric Cambisols and Albic Cambisols (formerly known as brown podzolized soils). The soils of these subtypes dominate over large areas in the mountain regions where parent material is composed of sandstone devoid of carbonates and other acid igneous or transformed rocks.

The paper describes Albic Cambisols and Hyperdystric Cambisols because, in addition to soil subtype, other criteria are required for their assessment. In the case of the least fertile soils, such as Haplic Podzols with an advanced podzolization process, and in the case of more fertile Cambisols, such as Epidystric Cambisols, Eutric Cambisols or Humic Cambisols (Eutric), the problems with diagnosing the quality of sites developed on such soils in the mountain regions should not occur. The detailed properties of Epidystric Cambisols and Eutric Cambisols in the mountain regions are given in Tables 9 and 10.

In the case of Haplic Podzols, a diagnosis of forest site types should contain the conditions of their location and associated climate characteristics. If Haplic Podzols occur at low elevations of the lower montane zone, the mountain mixed coniferous forest is a potential site type. On Haplic Podzols at higher elevations of the lower montane zone, known as upper sub-zone of the lower montane zone, the mountain mixed coniferous forests co-occur with the mountain coniferous forests on the borderline with the upper montane zone (Table 2). Their separation is largely based on the growth characteristics and productivity of spruce forests. Especially different site conditions, favourable in terms of soil trophism, are on Epidystric Cambisols, Eutric Cambisols and Humic Cambisols (Eutric). In the lowest sub-zone of the lower montane zone, these soils are covered by mountain fresh deciduous forests, while in the upper sub-zone – due to a reduced productivity caused by adverse climatic conditions – by mountain fresh mixed deciduous forests (Table 2).

The assessment of the productivity of Albic Cambisols is incomparably more difficult. It is an important

Table 2. Relationship of types and subtypes of mountain soils with types of sites in the zones

Type and subtype of soil (form of trophic)	Lower sub-zone of the lower montane zone[1]	Upper sub-zone of the lower montane zone[2]	Upper montane zone
R, PR, BRw, BRwy, BRs (eutrophic)	LGśw	LMGśw	BMWGśw
BRk (mezotrophic)	LGśw LMGśw	LMGśw BMGśw	BWGśw
BRb (oligo-mezotrophic)	LMGśw BMGśw	BMGśw LMGśw	BWGśw
Bw, Blw (oligotrophic)	BMGśw	BMGśw, BGśw	BWGśw

Symbols of type and subtype of soil: R – Rendzic Soil, PR –Calcaric Regosol, BRw – Eutric Cambisol, BRwy – Epidystric Cambisol, BRs – Cambisol Humic Eutric, BRk – Hyperdystric Cambisol, BRb – Albic Cambisol, Bw – Haplic Podzol, Blw – Podzol.

Symbols of forest site types: BWGśw –high-mountain fresh coniferous forest site, BGśw – mountain fresh coniferous forest sites, BMGśw – high-mountain fresh mixed coniferous forest site, BMGśw – mountain fresh mixed coniferous forest sites, LMGśw – mountain fresh mixed broadleaf forest sites, LGśw – mountain fresh broadleaf forest sites

[1] Lower sub-zone of the lower montane zone – extending from 500 (550) to 850 (900) metres a.s.l. in the Carpathian flysch, from 600 (650) to 1000 (1050) metres a.s.l. in the Tatras, from 450 (500) to 750 (800) metres a.s.l. in the Sudetes,

[2] Upper sub-zone of the lower montane zone (middle montane zone according to Alexandrowicz (1972)) – extending from 850 (900) to 1050 (1100) metres a.s.l. in the Carpathian flysch, from 1000 (1050) to 1200 (1250) metres a.s.l. in the Tatras, from 750 (800) to 950 (1000) metres a.s.l. in the Sudetes.

Note. In the case of certain location, specific soil was assigned by two forest sites (divided by a diagonal line) soil texture becomes a useful feature for distinguishing of forest site. In the case of loamy sand, sandy loam and light loam, potential productivity should be reduced, while sandy clay loam, loam, clay loam, silt clay loam and clay – should be increased.

Table 3. Selected properties of Albic Cambisols creating BMGśw at high elevations of the lower montane zone (mean values and standard deviations)

Horizon	pH	pH	Soct.	Skp.	V	Fractions (%)				Organic	Total N
	H_2O	KCl	$cmol_{(+)}kg^{-1}$	$cmol_{(+)}kg^{-1}$	(%)	> 2	0.1–0.02	< 0.02	< 0.002	C (%)	(%)
Ofh	3.4±0.1	2.7±0.1	3.2±1.3	6.4±2.3	6.8±1.5	-	-	-	-	26.4±6.5	1.2±0.2
AEes	3.6±0.2	2.8±0.2	0.5±0.1	1.5±0.7	6.0±2.6	26.7±17.3	20.3±2.6	23.8±5.1	10.9±2.8	4.6±1.6	0.3±0.1
BfeBbr	4.2±0.2	3.6±0.3	0.4±0.1	2.2±0.6	11.6±5.3	46.7±19.5	18.4±4.2	23.1±5.4	7.3±1.9	2.1±0.8	0.1±0.0
BC–C	4.6±0.1	4.0±0.1	0.4±0.1	1.4±0.7	13.3±6.2	82.8±3.6	16.6±3.7	21.8±4.9	6.3±1.7	-	-

Notes: AEes – top layers of mineral humus accumulation (humus-alluvial horizon), BfeBbr – saturation horizons, BC–C – deepest horizons (parent rock). pH w H_2O, pH in KCl, Soct. – sum of base cations determined in 1 M CH_3COONH_4, Skp. – sum of base cations determined by the Kappen method, V – base saturation

Table 4. Selected properties of Albic Cambisols creating LMGśw at high elevations of the lower montane zone (mean values and standard deviations)

Horizon	pH	pH	Soct.	Skp.	V (%)	Fractions (%)				Organic	Total N
	H_2O	KCl	$cmol_{(+)}kg^{-1}$	$cmol_{(+)}kg^{-1}$		> 2	0.1–0.02	< 0.02	< 0.002	C (%)	(%)
Ofh	3.4±0.1	2.7±0.1	4.0±0.6	8.2±2.0	9.3±2.9	-	-	-	-	25.7±5.1	1.3±0.2
AEes	3.6±0.2	2.8±0.2	0.7±0.2	3.0±0.7	9.3±1.6	22.5±16.7	25.1±1.7	35.9±10.5	16.5±6.7	4.9±1.7	0.3±0.1
BfeBbr	4.4±0.1	3.9±0.2	0.4±0.1	3.3±0.6	18.0±4.7	38.8±14.7	22.5±3.7	40.9±16.1	15.9±9.1	1.8±0.8	0.1±0.0
BC–C	4.7±0.2	4.1±0.2	0.5±0.1	2.9±0.3	22.5±8.5	77.0±16.2	17.3±2.8	40.5±16.0	14.9±8.8	-	-

Symbols as in Table 2

Table 5. Selected properties of Dystric Cambisols creating BMGśw at high elevations of the lower montane zone (mean values and standard deviations)

Horizon	pH	pH	Soct.	Skp.	V (%)	Fractions (%)				Organic	Total
	H_2O	KCl	$cmol_{(+)}kg^{-1}$	$cmol_{(+)}kg^{-1}$		> 2	0.1–0.02	< 0.02	< 0.002	C (%)	N(%)
Ofh	3.6±0.1	2.9±0.1	2.3±0.9	6.5±2.4	7.5±1.3	-	-	-	-	23.9±6.8	1.2±0.2
A	3.7±0.3	2.9±0.2	0.5±0.2	2.1±0.7	8.7±3.8	25.0±21.2	19.0±4.2	20.0±3.5	8.5±2.0	4.8±0.6	0.3±0.1
Bbr	4.2±0.1	3.5±0.1	0.3±0.2	2.1±0.3	10.3±4.9	57.5±10.5	18.5±9.2	20.0±4.0	5.5±1.5	2.0±0.8	0.1±0.0
BC–C	4.7±0.2	4.0±0.1	0.3±0.1	1.3±0.4	10.4±5.8	80.0±10.0	16.5±4.9	25.5±3.5	5.5±1.6	-	-

Symbols as in Table 2

subtype of Cambisols, frequent at higher elevations of the lower montane zone. Tables 3 and 4 specify the properties of the genetic horizons of Albic Cambisols forming the sites of mountain mixed coniferous and mountain mixed deciduous forests at high elevations of the lower montane zone. Despite a similar morphology and combination of genetic horizons, the Albic Cambisols of both types of sites differ in basic parameters deciding of the site quality. Table 11 presents the results of the assessment of the significance of differences between the mean values of the selected parameters in the respective genetic horizons of soils of the same subtype forming various forest sites at high elevations of the lower montane zone. The analysis confirms that the content of clay (< 0.002 mm) and the content of fractions < 0.02 mm in diameter are the factors that most strongly differentiate between Albic Cambisols of the mountain mixed coniferous and deciduous forests. The average content of clay fractions in the weathering of Albic Cambisols of mountain mixed coniferous forests

Table 6. Selected properties of Dystric Cambisols creating LMGśw at high elevations of the lower montane zone (mean values and standard deviations)

Horizon	pH H_2O	pH KCl	Soct. $cmol_{(+)}kg^{-1}$	Skp. $cmol_{(+)}kg^{-1}$	V (%)	Fractions (%)				Organic C (%)	Total N (%)
						> 2	0.1–0.02	< 0.02	< 0.002		
Ofh	3.5±0.2	2.8±0.1	5.0±1.6	9.0±1.1	9.8±2.8	-	-	-	-	30.0±8.6	1.3±0.3
A	3.7±0.1	3.0±0.1	0.9±0.3	4.0±1.3	11.1±3.4	19.3±11.0	32.6±6.1	38.0±10.4	17.9±2.8	6.7±1.8	0.4±0.1
Bbr	4.5±0.3	3.9±0.4	0.4±0.1	3.6±0.7	23.9±9.0	40.0±12.9	22.7±1.4	48.1±9.4	19.0±3.2	1.5±0.4	0.1±0.0
BC-C	4.5±0.3	4.0±0.1	0.5±0.2	2.6±0.7	22.3±7.4	77.1±6.4	20.6±2.9	41.9±7.4	17.1±2.7	-	-

Symbols as in Table 2

Table 7. Selected properties of Dystric Cambisols creating LMGśw at low elevations of the lower montane zone (mean values and standard deviations)

Horizon	pH H_2O	pH KCl	Soct. $cmol_{(+)}kg^{-1}$	Skp. $cmol_{(+)}kg^{-1}$	V (%)	Fractions (%)				Organic C (%)	Total N(%)
						> 2	0.1–0.02	< 0.02	< 0.002		
Ofh	3.6±0.2	2.8±0.2	4.9±2.3	10.4±2.9	9.6±2.5	-	-	-	-	31.1±6.3	1.4±0.3
A	3.6±0.1	2.8±0.1	0.6±0.2	3.1±1.6	9.9±3.6	26.0±20.0	26.6±6.3	28.5±4.4	11.4±2.6	4.7±2.0	0.2±0.1
Bbr	4.3±0.3	3.9±0.2	0.3±0.1	3.3±1.0	20.8±8.9	41.5±12.3	22.5±5.0	32.7±6.7	9.9±1.9	1.7±0.8	0.1±0.0
BC-C	4.6±0.2	4.1±0.2	0.3±0.2	2.3±0.7	23.4±7.1	77.0±15.1	21.2±4.5	30.6±17.3	10.4±7.5	-	-

Symbols as in Table 2

Table 8. Selected properties of Dystric Cambisols creating LGśw at low elevations of the lower montane zone (mean values and standard deviations)

Horizon	pH H_2O	pH KCl	Soct. $cmol_{(+)}kg^{-1}$	Skp. $cmol_{(+)}kg^{-1}$	V (%)	Fractions (%)				Organic C (%)	Total N (%)
						> 2	0.1–0.02	< 0.02	< 0.002		
A	4.0±0.2	3.2±0.2	1.4±0.7	6.5±2.7	17.4±3.0	15.8±12.7	31.0±5.1	41.8±9.8	17.2±4.4	6.1±2.1	0.4±0.1
Bbr	4.5±0.2	3.9±0.2	0.7±0.5	4.1±1.0	27.6±5.4	38.1±19.8	22.5±4.3	51.9±11.4	18.7±5.7	1.1±0.3	0.1±0.0
BC-C	4.9±0.3	3.9±0.2	2.4±2.0	5.1±2.0	36.0±10.9	76.2±18.4	19.2±4.9	50.9±12.7	20.7±7.9	-	-

Symbols as in Table 2

Table 9. Selected properties of Podzols creating BMGśw and BGśw at high elevations of the lower montane zone (mean values and standard deviations)

Horizon	pH H_2O	pH KCl	Soct. $cmol_{(+)}kg^{-1}$	Skp. $cmol_{(+)}kg^{-1}$	V (%)	Fractions in mm				Organic C. (%)	Total N (%)
						> 2	0.1–0.02	< 0.02	< 0.002		
Ofh	3.7±0.2	2.9±0.2	3.1±2.0	6.4±1.6	4.1±2.4	-	-	-	-	37.8±12.1	1.4±0.4
AEes	3.8±0.2	3.1±0.2	0.4±0.4	1.5±1.6	1.4±0.7	18.0±21.9	29.7±15.6	25.9±7.1	6.5±3.2	4.7±4.7	0.2±0.2
Bhfe	4.3±0.2	3.8±0.2	0.2±0.1	1.0±0.7	1.3±0.6	36.5±22.2	25.8±7.9	19.4±7.2	4.6±3.0	4.5±2.8	0.2±0.1
BC-C	4.6±0.3	4.2±0.3	0.1±0.1	0.5±0.2	2.2±1.1	72.5±18.7	24.3±7.8	20.1±8.5	5.2±2.9	1.31±1.29	0.1±0.1

Symbols as in Table 2

Table 10. Selected properties of Meso-eutric Cambisols creating LGśw at low elevations of the lower montane zone (mean values and standard deviations)

Horizon	pH H_2O	pH KCl	Soct. cmol$_{(+)}$kg^{-1}	Skp. cmol$_{(+)}$kg^{-1}	V (%)	Fractions in mm (%)				Organic C (%)	Total N (%)
						> 2	0.1–0.02	< 0.02	< 0.002		
A	4.3±0.3	3.4±0.3	2.0±1.8	4.0±2.4	9.7±7.9	26.6±32.4	28.7±12.0	33.7±13.4	8.4±6.6	2.8±2.0	0.2±0.2
Bbr	4.7±0.4	3.8±0.2	2.7±3.8	4.9±5.2	19.9±23.6	43.6±25.5	26.9±11.1	36.8±14.2	9.2±6.8	1.4±1.1	0.1±0.1
BC–C	5.4±0.6	4.1±0.5	7.8±6.6	12.9±9.1	53.6±27.6	67.0±29.4	25.0±11.2	36.0±15.4	10.6±9.4	0.7±0.6	0.1±0.1

Symbols as in Table 2

are by approximately 6–8% lower than the content of these fractions in the respective genetic horizons of the soils of mountain mixed deciduous forests; the differences in the content of fractions < 0.02 mm reach 12–18% in subsequent soil horizons, respectively (Tables 3 and 4). The differences in the content of fractions < 0.02 mm in the subsequent horizons of Albic Cambisols of the mountain mixed coniferous and mountain mixed deciduous forests in the upper sub-zone of the lower montane zone are shown in Figure 1a–c. The difference in the content of fine fractions in the soils under study is found to be associated with a different content of exchangeable base cations and in the degree of saturation with these cations (Tables 3 and 4).

At low elevations (in the so-called lower sub-zone) of the lower montane zone, Albic Cambisols are infrequent. In the relatively mild climate prevailing in this zone, Albic Cambisols are mostly covered by mountain fresh mixed deciduous forests and only occasionally by mountain fresh mixed coniferous forests. As in the upper sub-zone, the soils of mountain mixed coniferous forests differ in a higher content of coarse particles which, in fine earth fractions, consist of loamy sands, sandy loams or light loams. Mountain mixed deciduous forests growing on the weathering with the particle size distribution like that of loams, silty loams or silty clay loams are more productive (Table 2). The weathering with the particle size distribution like that of loams silty loams or silty clay loams on which mountain mixed deciduous forests grow is more productive (Table 2).

Hyperdystric Cambisols are another subtype of Cambisols widespread in the lower montane zone. Such soils can derive from the weathering of all non-carbonate massive rocks – sandstones, granites, gneisses, greywackes, crystalline schists, quartz porphyries and even amphibolites, greenschists or basalts. The analysis of the research material shows that at low elevations of the lower montane zone, Hyperdystric Cambisols form the site of mountain fresh deciduous or mountain fresh mixed deciduous forests. In the upper sub-zone of the lower montane zone, climate has a limiting effect on site productivity. Mountain fresh mixed deciduous and mountain fresh mixed coniferous forests co-occur on the same type of soil (Table 2). The averaged values of the properties of Hyperdystric Cambisols (broken down into genetic horizons) of the mountain mixed coniferous and mountain mixed deciduous forests in the upper sub-zone of the lower montane zone are given in Tables 5 and 6. The properties of Hyperdystric Cambisols of the mountain mixed deciduous and mountain deciduous forests in the lower sub-zone of the lower montane zone are presented in Tables 7 and 8a.

Hyperdystric Cambisols of the mountain mixed coniferous and mountain mixed deciduous forests at high elevations of the lower montane zone differ mainly in particle size. These differences are reflected especially in the percentage content of fine earth fractions – fractions < 0.02 mm and the smallest clay fraction (< 0.002 mm) which are important in all genetic horizons (Table 11). The weathering of Hyperdystric Cambisols of mountain mixed deciduous forests contains, on average, 12–28% more fractions < 0.02 mm and 9–14% more clay fractions, compared with the Hyperdystric Cambisols of the mountain mixed coniferous forests (Tables 5 and 6). Differences in the content of fractions in these soils are also illustrated in Figure 2a–c. Differences in the content of silt fraction are important in the mineral-humus and bedrock horizons of the soils under review. Different clay content in the weathering of Hyperdystric Cambisols results in a different content of exchangeable base cations and a different degree of saturation of the sorption complex by these cations visible in all genetic horizons (Table 11). Moreover, the humus accumulation horizons of Hyperdystric Cambisols in mountain mixed deciduous and mountain mixed coniferous forests differ in the content of organic carbon and total nitrogen.

Table 11. The level of significance of differences between the properties in genetic horizons of soils creating diverse forest sites ($p < 0.05$, nonparametric HSD test)

TSL	Soil	Horizon	pH H_2O	pH KCl	Skp. $cmol_{(+)}kg^{-1}$	V (%)	Fractions				Organic C (%)	Total N (%)	C/N
							> 2 mm	0.1–0.02	< 0.02	< 0.002			
BMG-LMG (WRD)	BRb	AEes	0.4682	0.7081	0.0005	0.0081	0.5614	0.0008	0.0093	0.0418	0.7156	0.3307	0.4887
		BfrBbr	0.0213	0.0546	0.0027	0.0222	0.4364	0.0572	0.0085	0.0175	0.6112	0.3792	0.0051
		BC-C	0.6948	0.7127	0.0002	0.0247	0.5596	0.6821	0.0055	0.0142	-	-	-
BMG-LMG (WRD)	BRk	A	0.7810	0.9238	0.0011	0.1698	0.4595	0.0002	0.0003	0.0002	0.0103	0.0052	0.1999
		Bbr	0.0100	0.0091	0.0002	0.0006	0.0016	0.1695	0.0002	0.0002	0.1424	0.0524	0.0002
		BC-C	0.3027	1.0000	0.0004	0.0004	0.2040	0.0402	0.0002	0.0002	-	-	-
LMG-LG (NRD)	BRk	A	0.0002	0.0002	0.0032	0.0002	0.1951	0.0973	0.0014	0.0023	0.1409	0.0276	0.0023
		Bbr	0.0855	0.8992	0.0906	0.0439	0.6883	0.9854	0.0004	0.0004	0.0201	0.9016	0.0002
		BC-C	0.0038	0.1151	0.0009	0.0071	0.9198	0.3617	0.0060	0.0075	-	-	-

Notes: TSL – compared forest site types, WRD – upper sub-zone of the lower montane zone, NRD – lower sub-zone of the lower montane zone, Skp. – sum of base cations determined by the Kappen method, V – base saturation

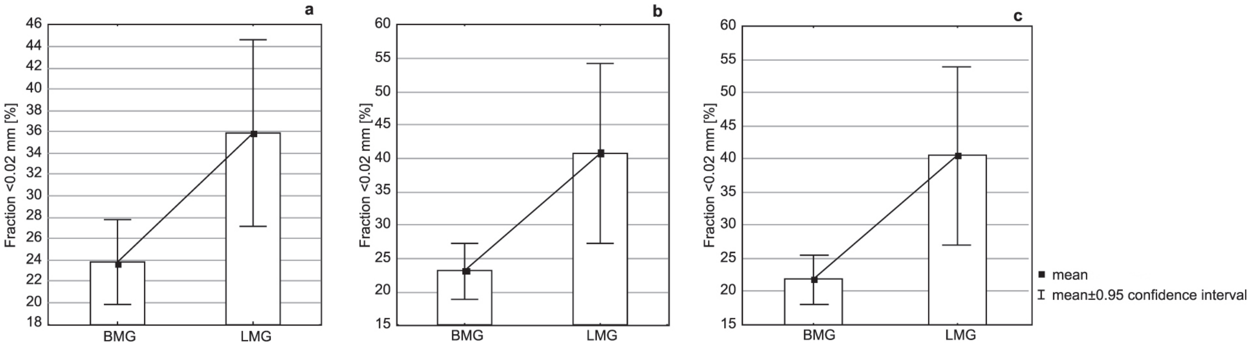

Figure 1. Average content of fraction <0.02 mm in horizon of Albic Cambisol of BMGśw and LMGśw at high elevations of the lower montane zone: a) humus-mineral horizon (AEes), b) cambic horizon (BfeBr) c) parent rock horizon (C)

At low elevations of the lower montane zone, the characteristics of the Hyperdystric Cambisols of mountain mixed deciduous and mountain deciduous forests differ in the same characteristics as Hyperdystric Cambisols at higher elevations of the lower montane zone (Table 7 and 8). The difference in the content of silt fractions in the genetic horizons of Hyperdystric Cambisols is on average 14–20% (the content of this fraction in the soils of the mountain deciduous forest is higher) (Fig. 3a–c). The Hyperdystric Cambisols of the mountain deciduous forests contain on average 6–10% more clay in fine earth fractions than the soils of the same subtype of the mountain mixed deciduous forests. Other characteristics of these soils – pH, exchangeable base cations, saturation with these cations as well as nitrogen content and C/N ratio in the mineral-humus horizons, differ in the horizons of humus accumulation and deepest horizons of Hyperdystric Cambisols, as expressed in the values shown in Table 11.

4. Discussion

The research, whose results are being presented, is a continuation and at the same time a contribution to the mountain habitat studies conducted by typologists from the so-called Cracow school. The pioneer studies concerning mountain site assessment were carried out by Alexandrowicz (1960, 1962) in Beskid Śląski and

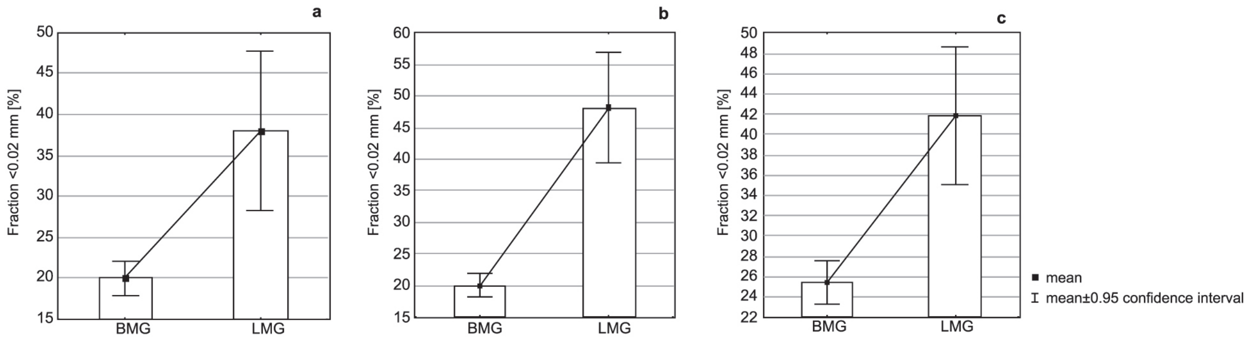

Figure 2. Average content of fraction < 0.02 mm in the horizon of Dystric Cambisols of BMGśw and LMGśw at high elevations of the lower montane zone a) humus-mineral horizon (A), b) cambic horizon (Br), c) parent rock horizon (C)

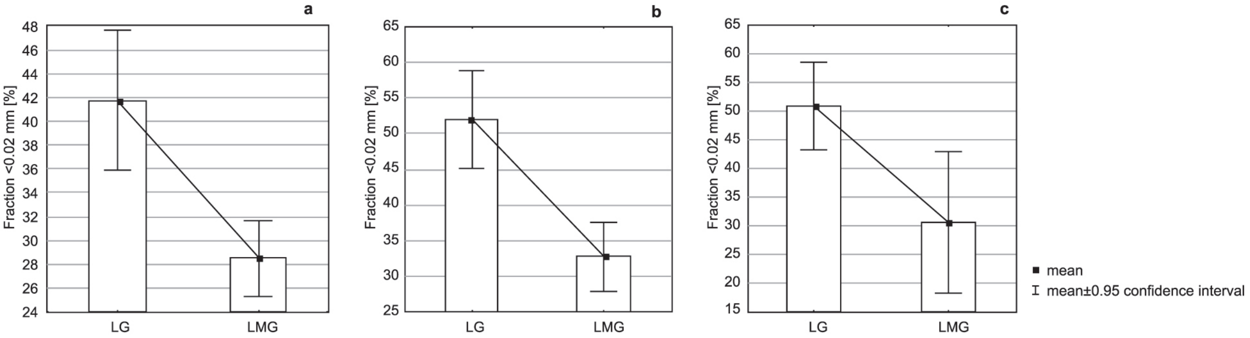

Figure 3. Average content of fraction < 0.02 mm in the horizon of Dystric Cambisols of LGśw and LMGśw at the lower montane zone a) humus-mineral horizon (A), b) cambic horizon (Br), c) parent rock horizon (C)

Beskid Żywiecki. Alexandrowicz was the first to propose distinguishing the upper sub-zone of the lower montane zone (the so-called middle montane zone) as the zone with a reduced forest production potential. He defined basic relationships between interactions of site types and parent rock in a given montane zone. The authors adopted Alexandrowicz's concept to divide the lower montane zone into two sub-zones differing in climatic conditions and forest-production capacity. The results of the research confirm the differences occurring between the sites of both lower and upper sub-zones of the lower montane zone and the need for a separate valuation of the soils developed in each of the sub-zones. The need for such separate valuation was realized by the typologists from the Cracow school who used it in their research dealing with the assessment of mountain sites (Baran 1968, 1996; Sikorska 1997, 1999).

With the lack of detailed soil analysis data in earlier studies, more attention in the assessment of site conditions was given to the type of bedrock. For example in Beskid Śląski, Alexandrowicz (1960) linked the Istebna rock layers in the lower sub-zone of the lower montane zone with the LMG habitat. He did not specify characteristics distinguishing between BMG and LMG in the upper sub-zone of the lower montane zones, but treated them as a specific 'complex of sites'. In the area of the Magura rock layers, Alexandrowicz (1962) described the sites as a 'trophic monolith' and distinguished one type of site – LG in the low sub-zone of the lower montane zone. The authors of this study do not diminish the role of the underlying bedrock in shaping the quality of mountain sites. They only attempt to draw attention to the fact that bedrock may feature a certain variability, which makes it difficult to draw direct conclusions about site quality based on the same type of bedrock alone. The presented study shows that, on various non-carbonate rocks at low and high elevations of the lower montane zone, different sites are formed on the same soil subtype and type of bedrock. This phenomenon particularly applies to the widespread Albic Cambisols and

Hyperdystric Cambisols. In such a case, distinguishing between sites should be based on detailed soil criteria, especially particle size distribution of rock weathering. The soils of the same subtype, but more abundant in fine fractions (< 0.02 mm) are more productive under certain climatic conditions (in the same sub-zone) than the soils less abundant in the said fractions. The higher content of fraction < 0.02 mm in diameter is associated with a higher nutrient content in the weathering material and better water retention properties. Clays and organic matter are the basic components capable of physico-chemical sorption processes, responsible for the effective sorption capacity of cations in the soil (Gruba 2012). Furthermore, they contribute to improving soil structure (Paluszek 2011), thus affecting the biochemical properties of soil and increase its fertility (Chakrabarti et al. 2004; Gianfreda et al. 2005). Clay also forms stable bonds with soil organic matter, thus increasing its stability and resistance to biochemical decomposition (Pastuszko 2007).

Soil particle size distribution is a characteristic that was previously used in the assessment of soil fertility in forest lowlands and uplands in Poland. Brożek et al. (2007, 2011) formulated a numerical indicator of the fertility of forest soils – Soil Site Index (SIG), taking into account the total content of fractions < 0.02 mm in a soil pedon of 1.5 m^3. The authors of the study have demonstrated that an increase in the content of fractions < 0.02 mm in the soil is associated with an increase in the fertility of soils and forest sites. This study is also an attempt to use soil particle size distribution in the assessment of the quality of mountain soils. The authors do not propose to assess soil quality using a numerical index, but rather suggest to supplement the traditional approach based on the assessment of soil types and subtypes with the valuation of selected measurable soil parameters. The more detailed criteria of determining soil potential productivity proposed by the authors are applicable whenever the diagnosis of the soil type or subtype is insufficient to assess its productivity. The study can be useful for a more detailed specification of the soil criteria to diagnose mountain site types included in the obligatory habitat-related documents (Ecological basis of silvicultural management (Siedliskowe podstawy hodowli lasu, 2004); Instruction on forest management planning (Instrukcja urządzania lasu, 2012)).

The reference of the characteristics of mountain forest site types obtained in this study to the site classification units distinguished in the neighbouring countries is difficult because of the different classification systems used. In the Slovak and Ukrainian Carpathians, where natural conditions are most similar, floristic systems of site classification are used (Randuška 1977; Gieruszyński 1988); at similar elevations in the regions where Cambisoils occur, they distinguish mainly beech, beech-fir or spruce-beech-fir forests.

5. Summary and results

Climate is the main factor determining the productivity of forest sites in mountain regions. A detailed evaluation of soil quality and its impact on the productivity of forest sites should take into consideration the climatic characteristics of different montane zones. The presented study confirms the need to distinguish the upper sub-zone of the lower montane zone being a transition zone between the low sub-zone of the lower and upper montane zones. It can be assumed that at high elevations of the lower montane zone, soils having similar physical and chemical properties are less productive by about one site class compared with similar soils developed in the lower montane zone. For example, the soil on which fresh mountain deciduous forests grow at low elevations of the lower montane zone will be the site of fresh mixed deciduous mountain forests at high elevations of the lower montane zone and of high-mountain coniferous forests in the upper montane zone.

The particle size distribution of weathering used for the assessment of the quality of mountain soils and sites can be particularly useful in the case of dominant soils – Hyperdystric Cambisols and Albic Cambisols. A general rule that should be adopted for these two soil subtypes is that the higher is the content of fine particles in the weathering like –sandy clay loams, loams, silty clay loams, clay loams and loams, the higher is the content of nutrients and, therefore, the greater productivity of a site for growing forest trees. The weathering less abundant in fine fractions like –loamy sands, sandy loams and light loams – combine with the less fertile sites. When the particle size distribution varies in the horizon profile, the particle size distribution in the horizons with the highest thickness should be taken into account.

With regard to the subtypes of soils of different fertility, the role of particle size distribution in the assessment of site quality is smaller. Cambisols and Podzols in the mountains develop on a highly permeable rock and sand weathering, whereas Epidystric Cambisols or Eutric Cambisols are characterised by favourable chemical properties and therefore the particle size distribution of these soils is less important.

To evaluate the productivity of mountain soils, a simple tool was developed involving climate zonation, as well as soil type and subtype including particle size distribution of rock weathering.

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Author's contribution

J.L., E.B. – concept, assumptions, interpretation of the results, text preparation and editing.
M.Z., T.W. – fieldwork, soil sampling.

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