Ekológia (Bratislava) Vol. 32, No. 2, p. 158–172, 2013
doi:10.2478/eko-2013-0014

SOIL MICROMYCETES AND VEGETATION CHANGES ASSOCIATED WITH VEGETATIVE COVER DESTRUCTION ON CHOSEN LOCALITIES OF TATRY MOUNTAINS – FIRST APPROACH

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Abstract

Ďugová O., Barančoková M., Krajčí J., Barančok P.: Soil micromycetes and vegetation changes associated with vegetative cover destruction on chosen localities of Tatry Mountains – first approach. Ekológia (Bratislava), Vol. 32, No. 2, p. 158–172, 2013.

Species composition of soil micromycetes and vegetation and its changes associated with vegetative cover destruction were observed in four localities of Tatry Mts. Three research plots with different extent of vegetation destruction on each locality were subjectively chosen: control plots with almost no destruction of vegetation and soil cover (C), partially disturbed plots (B) and plots with high level of soil cover destruction where cover of herb layer was less than 20% (A). Plant species composition of control plots was characterised by the highest level of taxonomical diversity, highest cover of herb and moss layer and represented by alpine herb and grass communities on siliceous bedrock (*Juncion trifidi* alliance) and alpine and subalpine plant communities on calcareous bedrock (*Seslerion tatrae* alliance). Devastation of soil and vegetation on B and A plots was performed particularly by decreasing of herb layer cover and changes in species composition: species as *Vaccinium myrtillus*, *Vaccinium vitis-idaea* and *Calluna vulgaris* were absent, whereas *Poa alpina*, *Potentilla aurea*, *Agrostis rupestris* or *Avenella flexuosa* occurred on devastated plots often. From investigated soils 43 species of soil micromycetes were identified. Control plot of each locality was represented by the highest taxonomical diversity of soil micromycetes. The number of species significantly decreased on plots with successive destruction of vegetation cover (B and A). Several species were identified in just one case (*Penicillium digitatum* (pers.:Fr.) Sacc., *Chrysosporium keratinophilum* D.Frey ex J.W. Carmich. etc.). The outcomes showed that soil microorganisms as well as vascular plants react on destruction of soil cover very sensitively.

Key words: soil micromycetes, alpine and subalpine vegetation, destruction of soil and vegetation cover, Tatry Mts.

Introduction

Vysoké and Belianske Tatry Mts are from the botanical point of view one of the most valuable territories of Slovakia, particularly their alpine and subalpine vegetation belt is very rich of rare and endemic species of Tatry Mts and Western Carpathians as well (Piscová, 2011).

Vascular plants and other living organisms exist in the ecosystems not separately but form special interactions among themselves, particularly plants and soil micro-organisms, because of their common soil environment. Plants gain the soil nutrients, which represent the products of decomposition and synthesis of micro-organisms and other processes carried in soil ecosystem as mineralisation, humification and other substance cycles. Vice versa, plants influence composition of microbial community by their root exudates especially in the rhizosphere. Plants with micro-organisms create dynamic ecosystem, which depends on the complex of ecological and anthropogenous factors (Ďugová, 2010, 2011; Šimonovičová, 2010).

The study area is pretty attractive for tourism especially because of its very high level of flora and fauna diversity and aesthetically impressive environment. On the other hand, the territory is very vulnerable due to specific geoecological conditions (Barančoková, Barančok, 2010) and hiking as a mechanical destructive element belongs in this area to anthropogenous factors negatively impact soil, vegetation and therefore soil micro-organisms. Trampling causes disturbance of vegetation cover, resulting to topsoil loss by water erosion and consequently changes in plant species composition particularly around touristic path and rest places (Piscová et al., 2011). Some species disappear due to changing growing conditions and increased attractiveness for plant collection activities (Barančok, 1999). Moreover, new alien floristic elements can interfere into natural vegetation composition of Tatry Mts (Šomšák et al., 1981).

This contribution deals with species composition changes of soil micromycetes and vegetation on chosen localities on the border between Vysoké and Belianske Tatry Mts (Fig. 1). It is just the first outcome of the long-term research aimed to investigate interaction between vascular plants and soil micromycetes in the alpine environment impacted by the touristic activity.

Material and methods

Four mountain saddles were chosen for the research. Basic geoecological information is summarised in Table 1.

T a b l e 1. Basic geoecological characteristics of the localities.

Locality	**Altitude (m a.s.l.)**	**Longitude N**	**Latitude E**	**Geology**	**Soil type WRB***	**Vegetation cover syntaxonomy alliance**
Predné Kopské sedlo saddle	1778	20°13´29″	49°13´60″	Werfenian shales	Skeletic Leptosol	*Juncion trifidi* Krajina 1933
Kopské sedlo saddle	1750	20°13´21″	49°13´60″	Werfenian shales	Skeletic Leptosol	*Juncion trifidi* Krajina 1933
Široké sedlo saddle	1825	20°12´78″	49°13´60″	Carpathian Keuper	Lithic Leptosol	*Juncion trifidi Krajina 1933*
Vyšné Kopské sedlo saddle	1933	20°13´11″	49°13´60″	Allgäu Member	Rendzic Leptosol	*Seslerion tatrae* Pawlowski 1935 corr. Klika 1955

* Soil types according to IUSS Working Group (2006)

Study area

Generally, the whole study area belongs to the cold region (Lapin et al., 2002). The characteristic of climate conditions are based on the data from the period between 1990 and 2010 (supplied by the Slovak Hydrometeorologic

Institute) from the closest meteorological stations situated in Skalnaté pleso (N: 49°11´22", E: 20°14´04", 1778 m a. s. l. Fig. 1). Average monthly temperature was -4.4 °C in January and 10.9 °C in July; average year sum of precipitation was 1435 mm (243 mm was the maximum in July). Permanent snow cover lasts usually from December to May, i.e. average of 174 days and average snow depth in winter time is 30 cm (from touch of snow to 170 cm in March 2009).

Fig. 1. Study area location.

Research plots sampling and phytosociology

Three research plots with different levels of soil and vegetation cover destruction on each locality were subjectively chosen: control plots with almost no vegetation and soil destruction, negative influence of the tourism was not remarkable (C); plots partially disturbed, vegetation cover was significantly impacted by the tourism and trampling, there was lower vitality of plant individuals but cover of vegetation was relatively high (B) and plots with high level of soil and vegetation destruction, cover of herb layer was less than 20% (A). Using Braun-Blanquet approach (Braun-Blanquet, 1964) phytosociological relevé was made on each plot (size approx. 2 × 2 m). Nomenclature of vascular plats is in compliance with Marhold, Hindák (1998) and syntax nomenclature follows publications Jarolímek, Šibík (2008) and Kliment et al. (2007).

Soil samples, isolation and identification of soil micromycetes

Soil samples were taken during vegetation period, from the depth of approx. 1–10 cm, from each research plot where phytosociological relevé were done. Microfungi were isolated using soil dilution plate method (Garret, 1981), dilution of 10^{-4}. Beer-wort agar, Sabouraud agar – all with rose Bengal and Czapek-Dox agar with chloramphenicol (200 mg L^{-1}) – were used as isolating media (Fassatiová, 1979). Petri dishes were cultivated at 25°C for seven days and then colonies of microfungi were counted and transferred to Czapek-Dox agar.

For determination of microfungi species the mycological keys and morphographs were used (e.g. Pitt, 1979, 1991; Ellis, 1971; Domsch et al., 1980; Nelson et al., 1983; Zycha et al., 1969).

Results and discussion

Forty-three species of soil micromycetes from 20 genera were isolated and identified from investigated soil samples. Of these, 16 species were common for all observed localities. The following six species were isolated just from one locality: *Absidia cylindrospora* Hagem, *Acremonium murorum* (Corda) W. Gams, *Circinella muscae* (Sorokin) Ber. & de Toni, *Penicillium digitatum* (pers.: Fr.) Sacc. recorded from Vyšné Kopské sedlo saddle, *Chrysosporium keratinophilum* D. Frey ex J. W. Carmich and *Penicillium commune* Thom from soil samples of Predné Kopské sedlo saddle. Genus of *Penicillium* was the most occurring from all identified genera with 14 species. The second common was the genus of *Aspergillus* with four species. Then genera of *Mucor*, *Mortierella* and *Absidia* each with three species succeeded. Other genera were represented by two or just one species. The dominance of species of the *Penicillium* genus in soil samples of Tatry Mts confirmed also literature references (Šimonovičová, 1992a, b). Species of this genus are regarded as cosmopolitan and it is possible to find them in all soils of our climatic zone, but their dominance is in montane and alpine environment (Ďugová, 2001, 2003). In comparison to *Penicillium*, less number of species of *Aspergillus* is explained due to its higher temperature demands and lower needs of soil moisture. Species of *Aspergillus* genus occurred much more in soils of southern regions of Slovakia (Ďugová, 2008; Ďugová et al., 2006).

Occurrence of species of *Apiosordaria verruculosa* (C. N. Jensen) Arx & W. Gams, *Chrysosporium keratinophilum* D. Frey ex J. W. Carmich, *Circinella muscae* (Sorokin) Ber. & de Toni and *Cylindrocarpon ianthothele* var. *majus* Wollenw. can be considered very valuable as these species have been isolated in Slovak soils just rarely (Šimonovičová, 2008; Šimonovičová, 2009). These species were isolated from studied soils samples just in 2011. Species composition of soil micromycetes is quite different on each locality. Number of species (on C plots) decreases in order from Vyšné Kopské sedlo saddle (38 species), Kopské sedlo saddle (35 species), Široké sedlo saddle (29 species) to Predné Kopské sedlo saddle (28 species) (Tables 2a through 5a; Fig. 2).

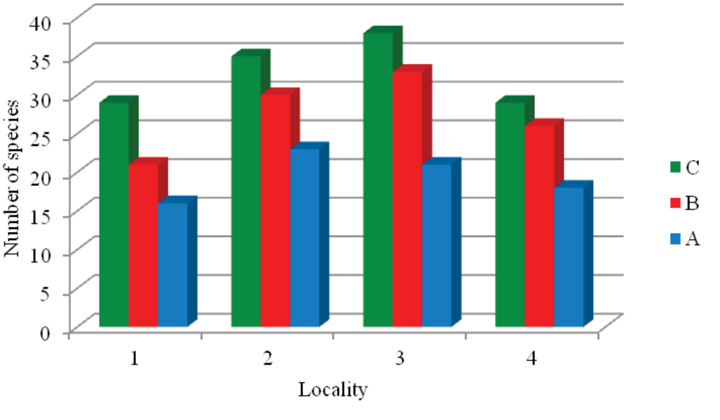

Fig. 2. Number of species of soil micromycetes on particular locality (1 – Predné Kopské saddle; 2 – Kopské saddle; 3 – Vyšné Kopské saddle; 4 – Široké saddle) (C – undisturbed plots, B – partially disturbed plots, A – plots with high level of destruction).

All in all 61 species of vascular plants were recorded on investigated localities. The highest number of species was observed on undisturbed plots (C) on each locality. On partially disturbed plots (B) the situation was a little different: in comparison to C plots on locality Široké and Predné Kopské sedlo saddles, the number of species decreased; vice versa on Kopské sedlo saddle and Vyšné Kopské sedlo saddle, where the number of species increased a little. Number of species on A plots (besides Kopské sedlo saddle) was the least (Fig. 3). Cover of herb layer was the highest on undisturbed C plots (90–95%) and decreased adequately to anthropic impact, on B plots 60–80% and A plots just 16% (Fig. 4).

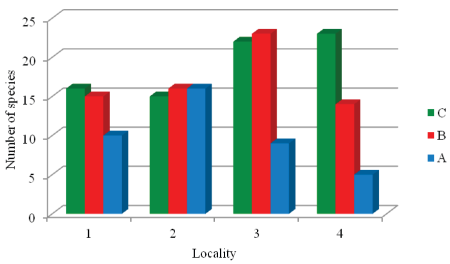

Fig. 3. Number of species on a particular locality (1 – Predné Kopské saddle; 2 – Kopské saddle; 3 – Vyšné Kopské saddle; 4 – Široké saddle) (C – undisturbed plots, B – partially disturbed plots, A – plots with high level of destruction).

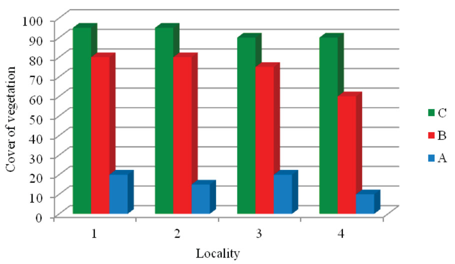

Fig. 4. Vegetation cover on a particular locality (1 – Predné Kopské saddle; 2 – Kopské saddle; 3 – Vyšné Kopské saddle; 4 – Široké saddle) (C – undisturbed plots, B – partially disturbed plots, A – plots with high level of destruction).

On the basis of our research supplied by literature (Piscová, 2010, 2011; Šomšák et al.,1981; Barančok, 1999), we could divide recorded vascular plants and soil micromycetes into three groups in order of their occurrence on plots with different levels of destruction (C, B, A).

1. Group: species recorded just on undisturbed plots C. Vascular plants: *Vaccinium myrtillus*, *Vaccinium vitis-idaea*, *Calluna vulgaris*. Micromycetes: *Mucor plumbeus* Bonord., *Aspergillus fumigatus* Fresen., *Penicillium citrinum* Thom. etc.
2. Group: species recorded on all plots no matter the level of disturbing. Vascular plants: *Poa alpina*, *Agrostis rupestris*, *Avenula versicolor*, *Potentilla aurea*, *Avenella flexuosa*, *Campanula alpina*, *Luzula alpinopilosa*, *Salix reticulata*, *Ligusticum mutellina*, *Thymus alpestris*, *Solidago virgaurea*, *Alchemilla* sp. Micromycetes: *Zygorhynchus heterogamus*, *Aspergillus niger*, *Trichoderma harzianum* and mainly some species of the *Penicillium* genus.
3. Group: species occurred just on the most disturbed A plots. According to Šomšák et al. (1981), these species can be considered as facultative synanthropic. Vascular plants: *Trifolium* sp. *Plantago media*, *Deschampsia cespitosa*, *Rumex alpinus*, *Taraxacum* sp. On these plots we did not identify any new species of soil micromycetes.

Survey of species composition of vascular plants and soil micromycetes for each locality:

First locality: Predné Kopské sedlo saddle (Tables 2a, b)

Typical species composition of alpine grass communities on siliceous bedrock included in alliance *Juncion trifidi* Krajina 1933 was recorded on control plot (C). *Agrostis rupestris*, *Vac-*

T a b l e 2a. Predné Kopské sedlo saddle (micromycetes).

Micromycetes	**C**	**B**	**A**
Alternaria alternata (Fr.: Fr.) Keissl.	+++	++	+
Apiosordaria verruculosa (C.N.Jensen)Arx & W.Gams	+++	+	+
Aspergillus versicolor (Vuil.) Tiraboschi	+++	++	+
Cladosporium cladosporioides (Fresen) G.A. de Vries	++	++	+
Fusarium sambucinum Fuckel	++	+	+
Mortierella gamsii Milko	+	+	+
Mortirella parvispora Linnem.	+++	++	+
Penicillium albidum Soop	++	+	+
Penicillium commune Thom	+++	+++	+
Penicillium glabrum (Wehmer)Westling	+	+	+
Penicillium chermesinum Biourge	+	+	+
Penicillium janczewskii K.M. Zalessky	+++	++	+
Penicillium roseopurpureum Dierckx	++	+	+
Rhizopus stolonifer (Ehrenb.)Vuill. var. *stolonifer*	++	+	+
Trichoderma harzianum Rifai	++	++	+
Zygorhynchus heterogamus (Vuill.)	++	++	+
Aspergillus niger Tiegh.	+	+	.
Fusarium oxysporum Schlechtdl.: Fr. [emend. Sny. & Hans pro maxima parte]	+	+	.
Mortierella bainieri Costain	+	+	.
Penicillium waksmanii K. M. Zalessky	+	+	.
Talaromyces flavus (Klöcker) Stolk &Samson	++	+	.
Absidia spinosa Lendn. var. *spinosa*	++	.	.
Aspergillus fumigatus Fresen.	+	.	.
Cylindrocarpon ianthothele var. *majus Wollenw.*	+	.	.
Doratomyces stemontis (Pers.: Fr.) F.J. Morton & G. Sm.	+	.	.
Chrysosporium keratinophilum D. Frey ex J.W. Carmich.	+	.	.
Mucor plumbeus Bonord.	+	.	.
Penicillium janthinellum Biourge	+	.	.
Number of species	28	21	16

cinium vitis-idaea, *Campanula alpina* dominate the herb layer. *Pulsatilla scherfelii* is quite common and almost all alpine grass species occurred. Shrubby species as *Vaccinium vitis idaea*, *Vaccinium myrtillus*, *Calluna vulgaris*, *Empetrum hermaphroditum* and *Pinus mugo* occurred just on this plot (C), just one seedling of *Pinus mugo* and few individuals of *Calluna vulgaris* occurred also on plot (B). The cover of herb layer decreased significantly on plot B. *Potentilla aurea* and *Agrostis rupestris* dominated, whereas species of *Vaccinium* genus and *Pulsatilla scherfelii* absolutely disappeared. Cover of herb layer was just 20% on A plot and species composition consist of *Poa alpina*, *Deschampsia cespitosa, Potentilla aurea*, few individuals of *Trifolium* sp. etc. Moss and lichens layer occurred just on undisturbed plot C and it is represented mainly by *Cetraria islandica* and *Polytrichum alpinum* with the cover of 70%. Presence of moss and lichens significantly decreased on B and A plots (moss layer cover just from 1 to 5%) (Table 2a).

From the point of view of soil micromycetes taxonomical diversity, the least number of species were isolated and identified on plot C of this locality. Species of *Penicillium* and *Aspergillus* genus were quite common; *Mucor*, *Absidia* and *Mortierella* occurred less (Table 2b).

T a b l e 2b. Predné Kopské sedlo saddle (vascular and non-vascular sp.).

Vascular species	C	B	A
	E_1 = 95%	**E_1 = 80%**	**E_1 = 20%**
Agrostis rupestris	3	2	+
Campanula alpina	3	1	+
Luzula alpinopilosa	1	1	+
Avenella flexuosa	1	1	+
Avenula versicolor	1	1	r
Carex sempervirens	1	+	.
Primula minima	+	+	.
Juncus trifidus	+	+	.
Pinus mugo	+	r	.
Calluna vulgaris	+	r	.
Vaccinium vitis-idaea	3	.	.
Pulsatilla scherfelii	+	.	.
Ligusticum mutellina	+	.	.
Vaccinium myrtillus	+	.	.
Empetrum hermaphroditum	+	.	.
Oreochloa disticha	r	.	.
Potentilla aurea	.	3	1
Alchemilla sp.	.	+	r
Doronicum stiriacum	.	r	.
Carex atrata	.	r	.
Hieracium alpinum	.	r	.
Poa alpina	.	.	2
Deschampsia cespitosa	.	.	1
Trifolium sp.	.	.	r
Number of species	16	15	10
Non-vascular species	**E_0 = 70%**	**E_0 = 5%**	**E_0 = 1%**
Polytrichum alpinum	2	1	.
Pleurozium schreberi	1	.	.
Polytrichum sp.	1	.	r
Cladonia coccifera	+	+	.
Cetraria islandica	3	.	.
Number of species	5	2	1

Explanationes: (C - undisturbed plot, B - mostly disturbed plot, A - disturbed plot, E1 - cover of herb layer, E0 - cover of moss and lichens layer)
Vascular and nonvascular plants: the old cover-abundance scale of Braun-Blanquet (r - one or few individuals, + - occassional, 1 - common, less than 5% cover, 2 - cover 5 - 25%, 3 - cover 26 - 50%, 4 - cover 51 - 75%, 5 - cover more than 75%), Micromycetes: + - rare, ++ - common, +++ - dominant).

According to gained data, the most sensitive species can be considered as *Absidia spinosa*. var. *spinosa*, *Mortierella baineri*, etc. These species were not identified from soil samples of disturbed plots B and A. On plot A, just 16 species were identified. It is the least from all investigated localities.

Second locality: Kopské sedlo saddle (Tables 3a, b)
Control, undisturbed plot C of this locality was classified within the alliance *Juncion trifidi*

T a b l e 3a. Kopské sedlo saddle (micromycetes).

Micromycetes	**C**	**B**	**A**
Absidia spinosa Lendn. var. *spinosa*	++	+	+
Aspergillus flavus Link: Fr.	+++	+++	+
Aspergillus fumigatus Fresen.	+++	+++	+
Cladosporium cladosporioides (Fresen) G.A. de Vries	+++	++	+
Microascus brevicaulis S.P. Abbott	+++	++	+
Mortierella gamsii Milko	+++	+++	+
Penicillium albidum Soop	+++	++	+
Penicillium chermesinum Biourge	+++	+	+
Penicillium citrinum Thom	+++	++	+
Penicillium decumbens Thom	+++	+	+
Penicillium funiculosum Thom	+++	++	+
Penicillium glabrum (Wehmer)Westling	+++	+++	+
Penicillium janthinellum Biourge	+++	++	+
Penicillium lividum Westling	+++	++	+
Penicillium roseopurpureum Dierckx	+++	++	++
Penicillium waksmanii K. M. Zalessky	+++	+	++
Talaromyces flavus (Klöcker) Stolk & Samson	+++	+	+
Trichoderma harzianum Rifai	+++	++	++
Zygorhynchus heterogamus (Vuill.)	+++	+++	++
Doratomyces stemontis (Pers.: Fr.) F.J. Morton & G. Sm.	++	+	+
Isaria farinosa (Hplm: Fr.) Fr.	++	+	+
Mucor plumbeus Bonord.	++	+	+
Rhizopus stolonifer (Ehrenb.)Vuill.var. *stolonifer*	++	++	+
Absidia glauca Hagem var. *glauca*	+++	++	.
Alternaria alternata (Fr.: Fr.) Keissl.	++	+	.
Aspergillus niger Tiegh.	++	+	.
Fusarium sambucinum Fuckel	+	+	.
Mucor hiemalis Wehmer f. hiemalis	++	+	.
Penicillium janczewskii K.M. Zalessky	++	+	.
Talaromyces wortmanii (Klöcker) C.R. Benj.	+	+	.
Aspergillus versicolor (Vuil.) Tiraboschi	+	.	.
Cylindrocarpon ianthothele var. *majus* Wollenw.	+	.	.
Fusarium oxysporum Schlechtdl.: Fr.[emend. Sny. & Hans pro maxima parte]	+	.	.
Mortierella bainieri Costain	+	.	.
Mortirella parvispora Linnem.	+	.	.
Penicillium brevicompactum Dierckx	.	.	.
Number of species	35	30	23

Krajina 1933. *Juncus trifidus* dominates; *Agrostis rupestris*, *Vaccinium vitis-idaea*, *Campanula alpina* and *Avenula versicolor* are quite common. *Vaccinium vitis-idaea*, *Vaccinium myrtillus*, *Oreochloa disticha*, *Juncus trifidus*, *Primula minima*, *Carex sempervirens* and *Pinus mugo* occurred just on this plot (C). Quite high level of diversity was recorded on partially disturbed plot (B). *Potentilla aurea*, *Agrostis rupestris* and *Avenula versicolor* dominate, other following species were recorded: *Homogyne alpina*, *Poa alpina*, *Deschampsia cespitosa*, *Solidago virgaurea*, and very few individuals of *Soldanella carpatica* and *Ranunculus pseudomontanus*. Species as *Plantago media*, *Phleum rhaeticum* and *Rumex alpinus* occurred just on A plot.

T a b l e 3b. Kopské sedlo saddle (vascular and non-vascular sp.).

Vascular species	C	B	A
	E_1 = 95%	E_1 = 80%	E_1 = 15%
Juncus trifidus	4	.	.
Agrostis rupestris	2	2	+
Campanula alpina	2	+	.
Vaccinium vitis-idaea	2	.	.
Avenula versicolor	2	2	+
Oreochloa disticha	1	.	.
Primula minima	+	.	.
Carex sempervirens	+	.	.
Avenella flexuosa	+	+	+
Vaccinium myrtillus	+	.	.
Hieracium alpinum	+	.	.
Pinus mugo	+	.	.
Bistorta vivipara	+	.	.
Potentilla aurea	+	3	1
Homogyne alpina	r	2	.
Deschampsia cespitosa	.	+	1
Solidago virgaurea	.	+	+
Trommsdorffia uniflora	.	+	r
Ranunculus pseudomontanus	.	+	r
Soldanella carpatica	.	+	r
Luzula alpinopilosa	.	1	.
Ligusticum mutellina	.	1	r
Phleum rhaeticum	.	1	+
Anthoxanthum alpinum	.	+	.
Poa alpina	.	+	.
Plantago media	.	.	+
Rumex alpinus	.	.	+
Alchemilla sp.	.	.	+
Oreogeum montanum	.	.	r
Senecio subalpinus	.	.	r
Number of species	15	16	16
Non-vascular species	E_0 = 50%	E_0 = 0%	E_0 = 1%
Polytrichum alpinum	2	.	.
Pleurozium schreberi	1	.	.
Polytrichum sp.	.	.	+
Cetraria islandica	1	.	.
Cladonia coccifera	+	.	.
Number of species	4	0	1

Explanations: (C - undisturbed plot, B - mostly disturbed plot, A - disturbed plot, E1 - cover of herb layer, E0 - cover of moss and lichens layer)
Vascular and nonvascular plants: the old cover-abundance scale of Braun-Blanquet (r - one or few individuals, + - occasional, 1 - common, less than 5% cover, 2 - cover 5 - 25%, 3 - cover 26 - 50%, 4 - cover 51 - 75%, 5 - cover more than 75%), Micromycetes: + - rare, ++ - common, +++ - dominant)

Thirty-five species of soil micromycetes were identified on C plot with quite high abundance. Species of *Penicillium* genus occurred also on B and A plots besides *Penicillium janczewskii* which was not isolated from A plot soil samples. Species of *Mortierella* genus are assessed as sensitive due to their occurrence just on undisturbed C plot. Thirty species were identified on B plot and 23 species on A plot.

Third locality: Vyšné Kopské sedlo saddle (Tables 4a, b)

The highest taxonomical diversity of vascular plants as well as soil micromycetes was observed on this locality. Plant communities on calcareous bedrock within the alliance *Seslerion tatrae* Pawlowski 1935 corr. Klika 1955 were found on control plot (C). *Sesleria tatrae*, *Salix reticulata* and *Dryas octopetala* dominated. Species as *Vaccinium vitis-idaea*, *Carex sempervirens*, *Pedicularis verticillata*, *Crepis jaquinii*, *Carex atrata* and *Leontodon hispidus* were recorded just on this plot. On the other hand species as *Silene acaulis*, *Scabiosa lucida*, *Gentianella lutescens* etc. appeared on partially disturbed (B) plot. A plot of this locality was characterised by low cover of herb layer (20%) and by the presence of species as *Poa alpina*, *Potentilla aurea*, *Agrostis rupestris*, *Taraxacum* sp. etc. One individual of *Cerastium arvense* subsp. *glandulosum*, subendemic species of Tatry Mts., was observed on this research plot as well.

The highest number of soil micromycetes were isolated and identified from soil samples of this locality. Species of *Penicillium* and *Aspergillus* genera dominated on control plot (C). Species as *Absidia cylindrospora*, *Cladosporium cladosporioides*, *Alternaria alternata* and *Penicillium digitatum* were assessed as sensitive due to their rare occurrence in samples from B plot but absolutely missed in samples from A plot.

Fourth locality: Široké sedlo saddle (Tables 5a, b)

Acidophilous grassy plant community within the alliance *Juncion trifidi* Krajina 1933 was observed on control plot (C). *Juncus trifidus*, *Pulsatilla scherfelii* and *Avenella flexuosa* dominated there. Species as *Calluna vulgaris*, *Vaccinium myrtillus*, *Vaccinium vitis-idaea*, *Carex sempervirens*, *Festuca supina* and *Pinus mugo* were recorded only on undisturbed plot (C). Partially damaged plot (B) was characterised by the dominance of *Potentilla aurea* and *Agrostis rupestris*. Plot with the highest extent of destruction (A) was characterised by very low cover of herb layer (10%) and following species composition: *Poa alpina*, *Agrostis rupestris*, *Avenella flexuosa*, *Solidago virgaurea* and *Potentilla aurea*.

Twenty-nine species of soil micromycetes were identified on C plot, 26 species on B plot and 18 species on A plot. *Absidia glauca* Hagem var. *glauca*, *Fusarium sambucinum* a *Mortierella baineri* reacted sensitively, they were isolated just in soil samples from C plot.

Conclusion

This article brings some new information about species composition of soil micromycetes and vascular plants in association to negative impacts of tourism in alpine environment. As the extent of destruction of vegetative cover increased, number and diversity of soil micromycetes decreased. Following species of soil micromycetes reacted very sensitively: *Absidia glauca* var. *glauca*, *Mucor plumbeus*, *Fusarium sambucinum* and particularly *Mortierella baineri*, identified just on undisturbed (C) plots.

T a b l e 4a. Vyšné Kopské sedlo saddle (micromycetes).

Micromycetes	**C**	**B**	**A**
Apiosordaria verruculosa (C.N.Jensen)Arx & W.Gams	++	+	+
Aspergillus flavus Link: Fr.	+++	+	+
Aspergillus niger Tiegh.	++	++	+
Cladosporium cladosporioides (Fresen) G.A. de Vries	+++	+	+
Cylindrocarpon ianthothele var. *majus* Wollenw.	++	+	+
Microascus brevicaulis S.P.Abbott	++	+	+
Penicillium albidum Soop	++	++	+
Penicillium brevicompactum Dierckx	+++	+	+
Penicillium decumbens Thom	+++	++	+
Penicillium funiculosum Thom	+++	++	+
Penicillium chermesinum Biourge	++	++	+
Penicillium lividum Westling	+++	++	++
Penicillium roseopurpureum Dierckx	++	++	+
Penicillium waksmanii K. M. Zalessky	++	+	+
Rhizopus stolonifer (Ehrenb.)Vuill.var. stolonifer	+++	++	+
Trichoderma harzianum Rifai	++	+	+
Zygorhynchus heterogamus (Vuill.)	++	++	++
Aspergillus versicolor (Vuil.) Tiraboschi	+	+	+
Fusarium oxysporum Schlechtdl.: Fr.[emend. Sny. & Hans pro maxima parte]	+	+	+
Mucor circinelloides Tiegh.f. circinelloides	+	+	+
Talaromyces wortmanii (Klöcker) C.R. Benj.	+	+	+
Absidia cylindrospora Hagem var. *cylindrospora*	+++	++	.
Absidia spinosa Lendn. var. *spinosa*	++	+	.
Acremonium murorum (Corda) W. Gams	+	+	.
Alternaria alternata (Fr.: Fr.) Keissl.	++	++	.
Aspergillus fumigatus Fresen.	+++	++	.
Fusarium sambucinum Fuckel	+	+	.
Mortirella parvispora Linnem.	++	+	.
Mucor hiemalis Wehmer f. *hiemalis*	+	+	.
Mucor plumbeus Bonord.	++	+	.
Penicillium glabrum (Wehmwr)Westling	++	+	.
Penicillium janthinellum Biourge	+	+	.
Talaromyces flavus (Klöcker) Stolk & Samson	+++	++	.
Absidia glauca Hagem var. *glauca*	+	.	.
Circinella muscae (Sorokin) Berl.& de Toni	+	.	.
Doratomyces stemontis (Pers.: Fr.) F.J. Morton & G. Sm.	+	.	.
Mortierella bainieri Costain	+	.	.
Penicillium digitatum (Pers.: Fr.) Sacc.	+	.	.
Number of species	38	33	21

Vascular plants reacted very sensitively as well. Tourism and its systematic attack cause mainly decreasing of vegetation cover and species diversity of vascular plants. On disturbed plots, native and threatened species gradually disappeared and more resistant species and occasionally apophytes were observed. Especially on A plots there are insufficient growing condition for vascular plants, soil loses its protective vegetation cover and some physical properties of soil getting worse. The most attacked places during the vegetation period are area of touristic path and rest places surroundings.

T a b l e 4b. Vyšné Kopské sedlo saddle (vascular and non-vascular sp.).

Vascular species	**C**	**B**	**A**
	E_1 = 90%	**E_1 = 75%**	**E_1 = 20%**
Sesleria tatrae	3	1	.
Salix reticulata	2	+	+
Dryas octopetala	2	2	.
Vaccinium vitis-idaea	1	.	
Potentilla aurea	1	.	1
Festuca picturata	1	+	.
Anthyllis vulneraria	1	1	.
Campanula tatrae	1	1	.
Ligusticum mutellina	+	+	+
Bartsia alpina	+	+	.
Bistorta vivipara	+	.	.
Pedicularis verticillata	+	.	.
Thymus alpestris	+	+	+
Homogyne alpina	+	.	.
Alchemilla sp.	+	.	+
Carex sempervirens	+	.	.
Galium anisophyllon	+	r	.
Crepis jacquinii	+	.	.
Oreochloa disticha	+	2	.
Androsace chamaejasme	r	+	.
Carex atrata	r	.	.
Leontodon hispidus	r	.	.
Silene acaulis	.	2	.
Scabiosa lucida	.	1	.
Primula minima	.	r	.
Arenaria tenella	.	r	.
Leucanthemopsis alpina	.	+	.
Gentianella lutescens	.	+	.
Saxifraga caesia	.	+	.
Luzula alpinopilosa	.	+	.
Bistorta vivipara	.	+	.
Avenella flexuosa	.	+	.
Poa alpina	.	1	2
Agrostis rupestris	.	.	+
Taraxacum sp.	.	.	+
Cerastium arvense ssp. *glandulosum*	.	.	r
Number of species	22	23	9
Non-vascular species	**E_0 = 5%**	**E_0 = 0%**	**E_0 = 0%**
Pleurozium schreberi	1	.	.
Number of species	1	.	.

Explanations: (C - undisturbed plot, B - mostly disturbed plot, A - disturbed plot, E1 - cover of herb layer, E0 - cover of moss and lichens layer)
Vascular and nonvascular plants: the old cover-abundance scale of Braun-Blanquet (r - one or few individuals, + - occassional, 1 - common, less than 5% cover, 2 - cover 5 - 25%, 3 - cover 26 - 50%, 4 - cover 51 - 75%, 5 - cover more than 75%), Micromycetes: + - rare, ++ - common, +++ - dominant)

T a b l e 5a. Široké sedlo saddle (micromycetes).

Micromycetes	**C**	**B**	**A**
Alternaria alternata (Fr.: Fr.) Keissl.	+++	++	+
Aspergillus flavus Link: Fr.	+++	++	+
Aspergillus fumigatus Fresen.	+++	++	+
Aspergillus versicolor (Vuil.) Tiraboschi	++	+	+
Microascus brevicaulis S.P. Abbott	+++	++	+
Mortirella parvispora Linnem.	+++	++	+
Mucor circinelloides Tiegh. f. *circinelloides*	+++	++	+
Penicillium albidum Soop	+++	+	+
Penicillium brevicompactum Dierckx	+++	++	+
Penicillium decumbens Thom	+++	+++	+
Penicillium funiculosum Thom	+++	+++	+
Penicillium janthinellum Biourge	+++	+	+
Penicillium janczewskii K.M. Zalessky	++	+	+
Penicillium lividum Westling	++	++	+
Penicillium roseopurpureum Dierckx	++	+	+
Penicillium waksmanii K. M. Zalessky	++	++	++
Rhizopus stolonifer (Ehrenb.)Vuill. var. *stolonifer*	+++	+	+
Trichoderma harzianum Rifai	+++	++	+
Acremonium murorum (Corda) W. Gams	++	+	.
Aspergillus niger Tiegh.	++	+	.
Apiosordaria verruculosa (C.N. Jensen)Arx & W. Gams	+	+	.
Cladosporium cladosporioides (Fresen) G.A. de Vries	+++	++	.
Penicillium citrinum Thom	++	+	.
Penicillium chermesinum Biourge	+++	++	.
Talaromyces flavus (Klöcker) Stolk & Samson	+++	++	.
Talaromyces wortmanii (Klöcker) C.R. Benj.	+	+	.
Absidia glauca Hagem ver. *glauca*	+	.	.
Fusarium sambucinum Fuckel	+	.	.
Mortierella bainieri Costain	++	.	.
Number of species	29	26	18

Acknowledgements

This work was supported by Slovak Grant Agency for Science VEGA, project No. 2/0055/11.

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T a b l e 5b. Široké sedlo saddle (vascular and non-vascular sp.).

Vascular species	**C**	**B**	**A**
	E_1 = 90%	**E_1 = 60%**	**E_1 = 10%**
Juncus trifidus	3	.	.
Avenella flexuosa	2	+	+
Pulsatilla scherfelii	2	.	.
Agrostis rupestris	1	2	+
Calluna vulgaris	1	.	.
Potentilla aurea	1	3	+
Campanula alpina	1	+	.
Vaccinium myrtillus	1	.	.
Carex sempervirens	+	.	.
Festuca supina	+	.	.
Ranunculus pseudomontanus	+	+	.
Luzula luzuloides	+	+	.
Hieracium alpinum	+	.	.
Trommsdorffia uniflora	+	+	.
Homogyne alpina	+	.	.
Vaccinium vitis-idaea	+	.	.
Ligusticum mutellina	+	+	.
Solidago virgaurea	+	+	+
Oreogeum montanum	r	.	.
Leucanthemopsis alpina	r	.	.
Pinus mugo	r	.	.
Soldanella carpatica	r	.	.
Bistorta major	r	.	.
Luzula alpinopilosa	.	+	.
Avenula versicolor	.	+	.
Anthoxanthum alpinum	.	+	.
Campanula tatrae	.	r	.
Poa alpina	.	1	1
Number of species	23	14	5

Explanations: (C - undisturbed plot, B - mostly disturbed plot, A - disturbed plot, E1 - cover of herb layer, E0 - cover of moss and lichens layer)
Vascular and nonvascular plants: the old cover-abundance scale of Braun-Blanquet (r - one or few individuals, + - occassional, 1 - common, less than 5% cover, 2 - cover 5 - 25%, 3 - cover 26 - 50%, 4 - cover 51 - 75%, 5 - cover more than 75%), Micromycetes: + - rare, ++ - common, +++ - dominant

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Ekológia (Bratislava) Vol. 32, No. 2, p. 173–185, 2013
doi:10.2478/eko-2013-0015

DOES MIST-NETTING PROVIDE RELIABLE DATA TO DETERMINE THE SEX AND AGE RATIOS OF MIGRATING BIRDS? A CASE STUDY INVOLVING THE GREAT TIT *(Parus major)* AND THE BLUE TIT *(Cyanistes caeruleus)*

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Abstract

Nowakowski J.K., Chruściel J., Muś K.: Does mist-netting provide reliable data to determine the sex and age ratios of migrating birds? A case study involving the Great Tit (*Parus major*) and the Blue Tit (*Cyanistes caeruleus*). Ekológia (Bratislava), Vol. 32, No. 2, p. 173–185 , 2013.

Ringing results of tits caught at two stations on the Polish Baltic coast were used to check if mist-netting could be successfully used to analyse the composition of sex and age classes of migrating birds. Four hypotheses are discussed, describing the distribution of age and sex classes during migration, and the consequences these distributions might have for the catching results. We analysed records of 59 000 Blue Tits and more than 84 000 Great Tits that were caught and we found a similarity in the results of catches at stations 188 km apart, and a higher similarity among catching sites 0.5–16 km apart. These results proved that mist-netting provides reliable data on the sex and age structure of migrating flocks, and that these data can generally be interpreted as representative for at least the area in a radius of more than 10 km. The results also showed a migratory divide through the central part of the Polish Baltic coastline between irruptive Blue Tits in the west and regular partial migrants in the east. Great Tits showed no tendency for irruptions anywhere in the study area. A high correspondence in the age and sex ratio was found for Great Tits and Blue Tits, in particular where both species are regular migrants. We found that the ratios of females and immatures did not differ by more than 1% over many years of study in these areas.

Key words: migration, methodology, sex ratio, age ratio, *Parus major*, *Cyanistes caeruleus*.

Introduction

Many studies have proved that the numbers of birds caught at ringing stations accurately reflect the migration dynamics of a species in the region of a station (Cofta, 1985; Svensson, 2000; Zehnder, Karlsson, 2001; Nowakowski, Busse, 2002; Nowakowski, 2002, 2003). Thus data of this type can be effectively used in the analyses of migration phenology (Peiro, 1997; Fowler, Hounsome, 1998; Schekkerman, 1999; Jenni, Kery, 2003), and for the seasonal or yearly migration intensity of certain species (Busse, 1994; Nowakowski, 1999; Sokolov et al., 2001). Using data from many ringing stations we can try to track a continental pattern of migration intensity and changes in the population size of each species (Woźniak, 1997; Nowakowski, Busse, 2002; Nowakowski, 2003; Nowakowski et al., 2005). Data from catches at ringing stations are also used to analyse the composition of the migrants' sex and age classes (Peiro, 1997; Nowakowski, 1999; Schekkerman, 1999; Scebba, 2001), and these results are considered to be representative of larger areas, or even of a whole country (Peiro, 1997; Nowakowski, 1999; Schekkerman, 1999; Scebba, 2001). But we did not find any evidence in the literature to justify this interpretation, and we formulated three hypotheses that questioned this interpretation:

1. The sex and age groups prefer slightly different habitats or local conditions, such as the catching localities' exposure to strong winds.

The wings of adult and immature birds have different flight properties (Alatalo et al., 1984; Hedenström, Pettersson, 1986; Mulvihll, Chandler, 1990; Arizaga et al., 2006), which affect their ability to counteract unfavourable weather and their need to seek places less exposed to predatory pressure. Birds of different ages and sexes might also prefer different types of food (e.g. Ebenman, 1986; Durell, 2000; Scheiffarth, 2001).

2. Individuals of higher social rank (usually older birds and males) (Saitou, 1979; Sandell, Smith, 1991; Gosler, 1993, 1996) choose more favourable habitats that are safer and provide more abundant food or better protection against unfavourable weather. They displace lower-ranked individuals to worse habitats (Woodrey, 2000; Newton, 2008).

Males might also establish territories during stopovers (Bibby, Green, 1980; Mehlum, 1983; Titov, 1999). Higher-ranked individuals in the flock might also defend resources during short stopovers and movements in short hops, the way tits migrate.

3. Different sex and age classes form groups during migration and tend to migrate together.

Immatures and adults of many passerines migrate separately. In spring males and females might migrate separately (Hussell et al.,1967; Ely, 1970; Gauthreaux, 1982; Francis, Cooke, 1986; Spina et al., 1994; Dierschke et al., 2005; Salewski, Bruderer, 2007). Even when different age and sex classes migrate at the same time, they might form flocks based on their sex and age because of the different flight properties of their wings (Arizaga et al., 2006).

If hypothesis 1 or 2 is true, the age and sex ratios of birds caught at ringing stations represent not only the general composition of the migrating population, but also reflect the habitat preferences of each group. Thus, the observed sex and age ratios would depend on the location of the mist nets, so catching birds in specific locations would increase the probability of ringing a bird of a particular sex or age. This would introduce a regular bias into the results, with an over-representation of some groups.

If hypothesis 3 is true, we cannot draw precise conclusions about the composition of age and sex classes among migrants by catching only a portion of the migrating birds, because we randomly catch only some flocks, each of which has a different composition to the mean of all the flocks moving through the area. But with highly intensive studies, conducted over a long period and at many sites that include most of the local micro-habitats at the same time, we can correctly estimate the age and sex ratios in populations, because the composition of age and sex classes of the captured birds would not differ from those of the migrating population in a regular manner.

We also formulated a fourth hypothesis as an alternative to the three earlier ones, which assumes the following:

4. The distribution of sex and age classes is uniform in a population migrating over large areas, and variable catching conditions do not affect the proportions of age and sex classes among the individuals that are caught. All individuals of the species share habitat preferences, and the conditions outside the stopover sites during migration do not favour the retention of a hierarchical structure in the flocks (as suggested by Surmacki, Nowakowski, 2007).

If the fourth hypothesis is true, the data on the sex and age ratios of the migrating population obtained at the ringing stations are reliable and would be representative of the migration over the larger area.

This study is aimed at verifying these four hypotheses.

When birds from different geographical populations migrate through a study area they might prefer different foraging and resting habitats, or they might use the different localities within the area at different intensities. In such a case the sex and age ratios of birds caught at a locality most closely reflect the composition of the most abundant population that uses this site. We would likely obtain different results by moving the catching site a few kilometres or to another habitat, even if the catches accurately reflect the composition of migrating populations at each locality.

So to verify which of the proposed hypotheses is true, we must select a species in which populations arriving from different directions at the study site do not mix. The Blue Tit (*Cyanistes caeruleus*) and the Great Tit (*Parus major*) fulfil this condition. They migrate on a broad front and on the same heading through the whole of Central and Eastern Europe. The migration routes of different populations in both these species do not cross (Winkler,1974; Frelin, 1974; Thielemans, Eyckerman, 1975; Hudec, 1983; Alerstam, 1993; Glutz von Blotzheim, Bauer, 1993; Latja, 1995; Nowakowski, 2003). Both species migrate relatively slowly (Dhondt, 1966; Frelin, 1979; Payevsky, 1971; Nowakowski, 2001, Nowakowski, Chruściel, 2004; Nilsson et al., 2008), "from one bush to the next" (Ulfstrand, 1962). This allows us to sample the whole population of migrants relatively accurately, not only the groups that use the ringing sites for longer stopovers.

Study site, materials and methods

Data were compared from nearby ringing localities that sampled the same migratory population, and between more distant areas where birds caught may come from different populations. These conditions are fulfilled by two ringing stations located on the Polish Baltic coast: Mierzeja Wiślana (MW) and Bukowo-Kopań (BK), located 188 kilometres apart (for a description of both stations see Nowakowski (2001)). At each of these stations in some years birds were caught simultaneously at two sites (referred to later in the text as the catching localities for each station).

Bukowo-Kopań in 1980 operated at locality BK1 (54°20´51″, 16°15´43″) and 3 kilometres away at locality BK2 (54°19´57″, 16°14´15″), in 1981-1982 at BK1 and 16 kilometres away at BK3 (54°27´11″, 16°24´18″). In 1995–1998, 2001 and 2003, localities BK3 and BK4 (54°27´46″, 16°24´38″) located 1.5 kilometres km apart were in operation. Station Mierzeja Wiślana in 1967-1968, 1971-1974, 1982-1983 operated at locality MW1 (54°21´15″, 19°18´56″) and at locality MW2 (54°21´10″, 19°19´21″) 0.5 km apart. These localities were exposed to different wind conditions. The most exposed localities were at BK3 and at MW2. Their habitats also differed slightly, with a different proportion of reeds, varying ages of trees, etc. Generally, at MW2 the habitat was slightly poorer than at MW1. Small woods of alder occurred at BK1 and BK3, which were absent at BK4. The proportion of low willow thickets with reeds was higher at BK4 than at the station's other localities.

Numerous movements of tits between the pairs of ringing localities up to 2 km apart were observed, often on the same day. This fact and also the short distance between the catching localities allow us to assume that tits from the same migratory populations were being caught at these stations. Only about a dozen movements were observed in any year from one locality to another 16 km away at the same station. Stations Mierzeja Wiślana and Bukowo-Kopań lie 188 km apart and very few direct movements of birds ringed at the one and recovered at the other were observed (one every few years). So we assume that the birds caught at these stations do not come from the same stream of migrants, though they probably are from migratory populations moving along nearby routes (Nowakowski, 2003). Busse (1973) presumed that the catches at Mierzeja Wiślana and Bukowo-Kopań stations comprised birds of different migratory populations (in different proportions in different years).

The material we analysed came from the autumn migrations between 1967 and 2003. The records included 28 047 Blue Tits and 50 041 Great Tits caught at Mierzeja Wiślana, and 30 945 Blue Tits and 34 639 Great Tits from Bukowo-Kopań. Each station operated for the whole migration season from mid-August until the end of October, and in some years longer, but not all of their ringing localities were operated throughout the season. To compare data between the stations we therefore analysed only material collected during the tits' migration, i.e. between 15 September and 31 October, and only from the main catching locality, which operated over the whole season and used the greatest number of mist nets. For comparisons between two nearby catching localities operating at a station, only data from identical periods were used. We omitted birds in juvenile plumage, which are seldom migrants, and individuals that had not been aged or sexed. No comparisons were made of catching localities for years when fewer than 20 individuals of a species were caught. For the Blue Tit that was locality MW2 in 1982, for the Great Tit it was MW2 in 1974.

In this paper we consider the differences and the similarities in the composition of age and sex classes among the studied groups of migrants. Questions about similarities are not answered by conventional statistical methods. Conventional statistical methods of analysing the frequency that a given phenomenon occurs are based only on the most probable value, and are thus imprecise (MacKay, 2003). In this paper we applied a direct approach, based on the beta distribution of the probability of the studied phenomenon, using the so-called Bayesian approach to statistical data analysis (Spiegelhalter, 1999).

If in a large population the proportion of females equals 'p' and detectability (the probability of being caught) does not depend on the sex, in any sample of N caught birds we would expect k ≈ p*N of females. More precisely, the number of females has the binomial distribution, which we symbolically express as: k ~ Binomial(p, N). The opposite approach, if based on a sample of N caught birds among which there are k females we want to draw conclusions about the possible values (distribution) of the proportion 'p' in a population we have to apply the beta distribution: p ~ Beta(k+1, N-k+1). To compare proportions of females in two samples (N_1,k_1) and (N_2,k_2), two hypotheses were formulated:

H1: each sample comes from a different population with different ratios of females: k1 ~ Binomial(p1, N1), and of males k2 ~ Binomial(p2, N2)

H2: both samples come from the same population with a common value for p: k1 ~ Binomial(p, N1), k2 ~ Binomial(p, N2)

Applying the Bayesian approach we can precisely calculate which of these hypotheses is more probable, and how many times more likely one hypothesis is than the other in the light of the available data:

$$\frac{P(H_1 \mid Data)}{P(H_2 \mid Data)} = \frac{Beta(k_1+1, N_1-k_1+1) \cdot Beta(k_2+1, N_2-k_2+1)}{Beta(k_1+k_2+1, N_1+N_2-k_1-k_2+1)} \quad (1)$$

An identical procedure was used in the analysis of the age structure. Two age classes were distinguished in these tits: birds in their first year of life (imm.) and birds in their second or later years of life (ad) (see Busse (1984) and Svensson (1992) for ageing and sexing methods for these tits).

Following Jeffreys (1961), we applied a comparative ranking of the probabilities based on the evidence (Table 1) and used a threshold value of 1 to indicate a significant difference or similarity. Positive evidence implies that hypothesis 1, where the samples originate from different populations, is more probable; negative evidence means that hypothesis 2, where the samples originate from the same population, is more probable.

Table 1. The evidence and its interpretation based on probability calculated for H1.
P_{H1} – probability H1; S_{H1} – odds for H1, $S_{H1} = P_{H1}/P_{H2}$; E_{H1} – evidence for H1, $E_{H1} = 2*\log10(S_{H1})$.

P_{H1}	S_{H1}	E_{H1}	Meaning evidence in favour of hypothesis H1
>0.76	>3.16	≥1	Substancial evidence
>0.91	>10	≥2	Strong evidence
>0.97	>31.6	≥3	Very strong evidence
>0.99	>100	≥4	Decisive evidence in favour of H1 (H2 may be rejected)

In testing the hypotheses for multiyear periods, an equation was applied for the total probability:

$P(H1|1\ to\ N) = P(H1|Y_1)\cdot P(Y_1) + P(H1|Y_2)\cdot P(Y_2) + ... + P(H1|Y_N)\cdot P(Y_N)$ (2)

where $P(H1|Y_N)$ is the probability of the hypothesis H1 in a year N; and $P(Y_N)$ is the probability of the year N. If the probabilities for each year $P(Y_N)$ are equal (as in this case), the equation can be represented in the form:

$P(H1|1\ to\ N) = [P(H1|Y_1) + P(H1|Y_2) + ... + P(H1|Y_N)]/N$ (3)

With the mean probability of H1 we can calculate the corresponding value of the evidence by the equation

$EH1 = 2 * [\log10(P(H1)) - \log10(1-P(H1))]$ (4)

The figures present 95% credibility intervals for p calculated on the beta distribution. The most probable value (the mode) was marked with the point pMOD = k / N.

Results

A similar composition of age and sex classes was observed in both species at both bird-ringing stations (Mierzeja Wiślana, MW, and Bukowo-Kopań, BK). Over the 37 years that we studied, females constituted 57.5% (±1.5%) of the caught birds and immatures constituted 90% (±2%) as presented in Table 2. An identical proportion of female Blue Tits was recorded at the MW and BK stations, which is strong evidence in favour of hypothesis H2 that both samples come from the same statistical population (Table 2). In the remaining cases differences were highly statistically significant, though relatively small if we consider that in both species the proportion of females and immatures fluctuate by more than 15% year to year.

The ratio of immature Blue Tits at BK varied the most, by as much as 4% from MW (Table 2). This result was caused by two years of irruptions. In 1999 and 2003 station BK caught 36% of all the Blue Tits that have been trapped over the 37 years of studies at this station. In these two years, immatures constituted 95% of all caught Blue Tits, a ratio that was significantly higher than in the non-irruptive years (irruptive years 1999 and 2003: imm. – 95%, N = 9 011; non-irruptive years: imm. – 89%, N = 16 207; $E_{H1} = 117.5$; Fig. 1). No irruptions of the Great Tit were noted at either station, or of the Blue Tit at station MW. The ratios of immature Blue Tits at MW and BK do not differ significantly in non-irruptive years (MW: imm. – 88%, N = 24 724; BK: imm. – 89%, N = 16 207; $E_{H1} = 0.4$).

The age and sex ratios were also similar for both species. The ratios of female Great Tits and Blue Tits at the MW station (where neither species irrupted) differed by only 0.5%, very strong evidence in favour H2 (*Parus major*: imm. – 58.2%, N = 47 446; *Cyanistes caeruleus*: imm. – 58.7%, N = 24 724; $EH_1 = -3.2$). Similarly, the ratio of immatures was significantly similar in both species, with the difference in mean ratios of only 0.6% (*Parus major*: imm. – 88.9%, N = 47 446; *Cyanistes caeruleus*: imm. – 88.3%, N = 24 724; $E_{H1} = -1.7$).

T a b l e 2. Comparison of sex and age ratios between the stations (all years pooled). F – females; Imm. – birds in their first year of life; E_{H1} – evidence in favour of hypothesis H1.

	F % (N)			Imm. % (N)		
	MW	**BK**	E_{H1}	**MW**	**BK**	E_{H1}
CY CAE	59 (24 724)	59 (25 218)	-3.8	88 (24 724)	92 (25 218)	55.2
PA MAJ	58 (47 446)	56 (31 176)	10.2	89 (47 446)	88 (31 176)	9.7

T a b l e 3. Comparison of sex and age ratios between the stations in different years (irruptive years excluded). Number of years with similar ratios (H2 more probable; $P_{H1} < P_{H2}$; $E < 0$), different ratios (H1 more probable; $P_{H1} > P_{H2}$; $E > 0$) and the evidence of mean probability calculated for all pairs of years (for *C. caeruleus* N = 31 years, for *P. major* N = 33 years) are given. Numbers of statistically significantly similar ($E \leq -1$) and different ($E \geq 1$) years are in brackets.

	CY CAE		PA MAJ	
	Sex	**Age**	**Sex**	**Age**
N similar years (significantly)	21 (14)	23 (15)	30 (28)	27 (25)
N different years (significantly)	16 (11)	14 (13)	7 (2)	10 (7)
E_{H1} for mean P_{H1}	>0.0	-0.1	-1.0	-0.6

The age and sex ratios for Great Tits and Blue Tits were similar for most years at both stations, implying H2 – that birds caught at MW and BK originate from the same statistical population – is more probable than H1, but in a few years both species showed a significantly different ratio of immatures or females (Table 3, Fig. 1). In both species the total similarity (Equation 3) calculated for the ratio of immatures or the ratio of females was always higher for H2 (MW and BK represent the same statistical population) than for H1 (MW and BK represent different statistical populations). However, the probability of H2 was significantly higher than of H1 (Table 3) only in the case of sex ratios in the Great Tit.

For the few years in which hypothesis H1 (different age ratios at each ringing station) was more probable we checked if the differences between the stations showed any regular character, i.e. if the ratio of females or of immatures was regularly higher at one of the stations. For each of these years the probability of hypothesis $H1_{BK}$ was calculated (higher ratio of females or of immatures at BK) and total probability of this hypothesis (Equation 3). The evidence of the total probability within the range $-1 < E_{H1BK} < 1$ means that in years when the sex and age ratios differed between the stations these differences did not have a regular character; $E_{H1BK} < -1$ means that in certain years at BK there were regularly more females or immatures than at MW; $E_{H1BK} > 1$ means that in certain years at BK there were regularly fewer females or immatures than at MW.

We found that the sex ratio for both species never showed a regular character: in some years the ratio of females was higher at BK, in others at MW (*Parus major* – $E_{H1BK} = 0.8$; *Cyanistes caeruleus* – $E_{H1BK} = -0.7$). But it was different with the age ratios. For both species in years when the ratio of immatures differed at BK and MW the differences showed a regular character. It was particularly clear in the case of the Blue Tit, where in each of 14 years with a

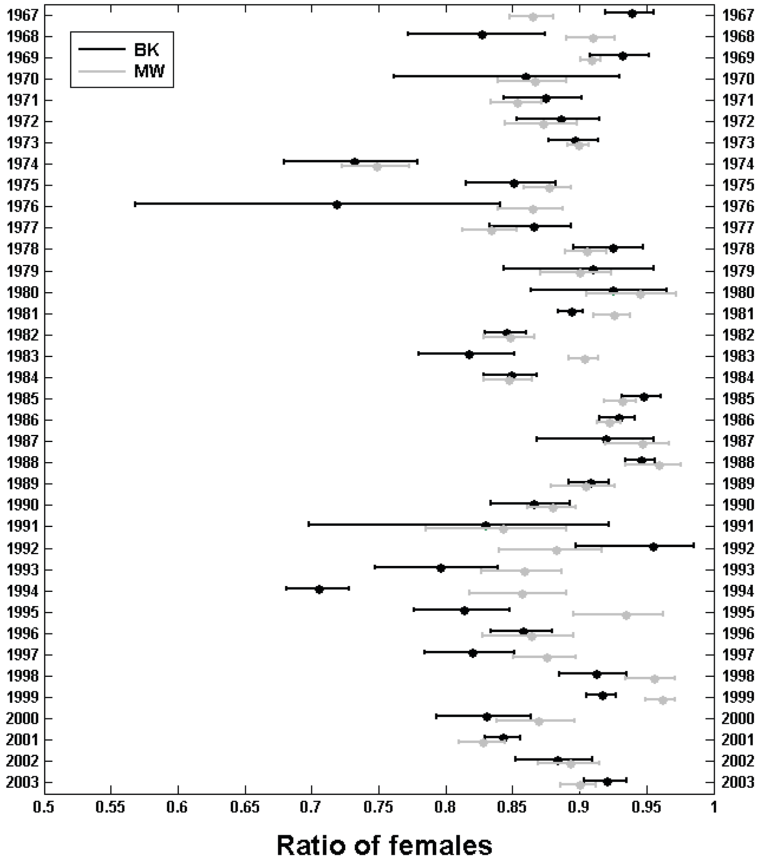

Fig. 1. Comparison of the proportions of immature Great Tits at stations Bukowo-Kopań (BK) and Mierzeja Wiślana (MW). Note that in the abundance of birds in 1977-1990 the ratio of immatures at both stations was usually similar (in 9 of 14 years the difference was less than 2%, which gives strong evidence in favour of H2), but in 1983 the difference was 9% (decisive evidence in favour of H1). The most probable value (mode) and 95% credibility intervals are marked in the figure.

significant difference a higher proportion of immatures was recorded at BK (E_{H1BK} = –2.8; in total in these years at BK – 93% imm., at MW – 84% imm.). In the Great Tit for the 10 years in which these differences were observed, immatures were more numerous at MW in 9 years (E_{H1BK} = 1.7; respectively BK – 87% imm., MW – 90% imm.).

Stronger similarities were noted among the nearby catching localities within each ringing station than between the stations, regardless of whether the catching localities were 0.5–3 or 16 km apart (Table 4). In these cases the total probability of H2 was also significantly higher than of H1 only when analysing the ratio of female Great Tits. In all 16 years the ratio of females was significantly similar (Table 4, Fig. 2). But even in the sex ratios of the Blue Tit, which showed the smallest similarities between the localities, in 9 years the ratios of females

T a b l e 4. Comparison of the age and sex ratios at pairs of catching localities at one station, located 0.5–3 km (A) and 16 km (B) apart. For other description see Table 3.

		CY CAE		PA MAJ	
		Sex	**Age**	**Sex**	**Age**
A	N similar years (significantly)	10 (8)	12 (9)	14 (14)	10 (9)
	N different years (significantly)	4 (3)	2 (2)	0 (0)	4 (3)
	E_{H1} for mean P_{H1}	-0.4	-0.8	-1.8	-0.5
B	N similar years (significantly)	2 (1)	2 (1)	2 (2)	2 (2)
	N different years (significantly)	0 (0)	0 (0)	0 (0)	0 (0)
	E_{H1} for mean P_{H1}	-1	-0.8	-1.5	-1.9
Together	E_{H1} for mean P_{H1}	-0.5	-0.8	-1.8	-0.6

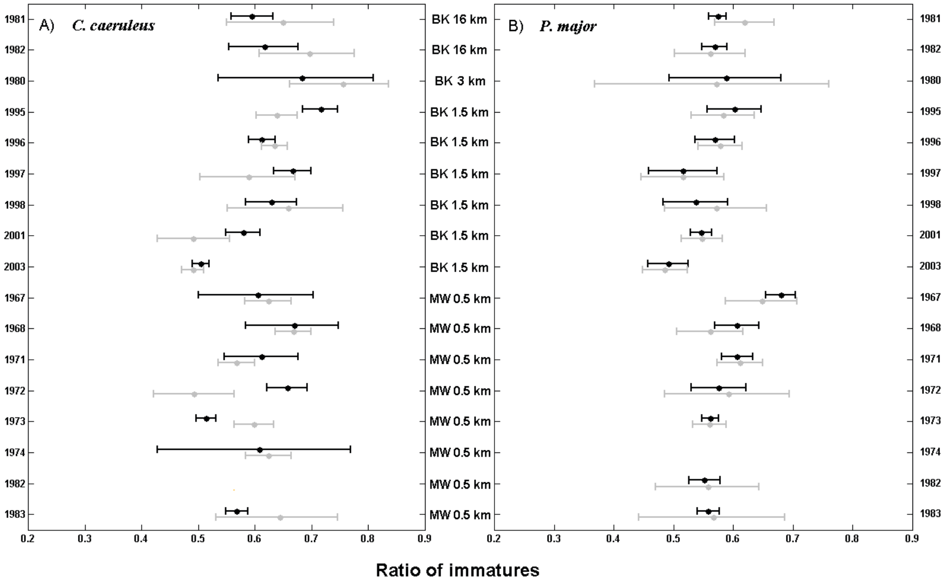

Fig. 2. Comparison of the ratios of female Blue Tits (A) and Great Tits (B) at pairs of catching localities at one station. For each pair of localities at the station, the year and the distance between the catching localities is given below the X axis. The most probable value (mode) and 95% credibility intervals are marked in the figures.

were significantly similar and only in 3 years were the ratios significantly different (Fig. 2; the total probability H2 – p = 0.65 was almost two times higher than the total probability H1 – p = 0.35). Year-to-year fluctuations in the ratios of females or the ratios of immatures observed at the stations provided good reference values to analyse the differences between the localities at the stations. Such a comparison was done for both parameters (the ratio of females and the ratio of immatures) in both species. The mean difference between years at the same locality was in all cases higher than the mean difference between the localities in the same year. But only in the case of the ratio of immature Great Tits was this result statistically significant (E_{H1} = 4.0).

It is difficult to determine unambiguously if the differences that were found between catching localities at one station had a regular character. No more than 2 years with a significant difference were noted at any pair of localities at one station at the same time, which impeded any statistical analysis. The data presented in Fig. 2a show that these differences lacked a regular character, even for the sex ratios of Blue Tits, which showed the greatest number of differences between the catching localities. In the 7 years when localities MW1 and MW2 were operating simultaneously, a significant similarity in the sex ratios of Blue Tits was found in 4 years, an unclear indication of the similarity in 1 year, and significantly different ratios in 2 years. In 1971 significantly more females were observed at MW1, and in 1972 at MW2 (Fig. 2a). The total probability of the hypothesis $H1_{MW1}$ – that at MW1 there were more females than at MW2 – equals the probability of the contrary hypothesis $H2_{MW1}$ – that at MW1 there were fewer females than at MW2 (for $H1_{MW1}$ $p = 0.494$, for $H2_{MW1}$ $p = 0.506$).

Discussion

Generally the high concordance of the results obtained at catching localities situated different distances apart at one ringing station, and even between the two stations located 188 km apart, showed that mist-netting provides reliable data on the age and sex ratios of migrating birds, and that these data are representative of a larger area with a radius of more than 10 km. The differences were no greater as the distance between the localities rose to 16 km, which indicated that the passage was relatively uniform for the sex and age ratios across larger areas (as assumed by hypothesis 4). Significant differences in the age and sex ratios of birds caught at nearby catching localities occurred only in a few years, but even then the differences were not regular. Thus no evidence was found that individuals of a different age or sex selected different habitats for their resting and foraging places. At least in these two species of tits, there was no confirmation for hypotheses 1 and 2.

Differences in the composition of age and sex classes occurred in some years even at the closest pairs of catching localities at station MW, where the central points of the mist-netting areas at MW1 and MW2 were only approx. 500 m apart, and some nets of one locality were only 100 m from the border of the other locality. For example, in 1968 at MW1 69% of the Blue Tits were immatures (N = 124), but at MW2 92% were immatures (N = 854) (see also Fig. 2). This local variation indicated that sometimes groups of birds with very different age and sex ratios occurred at a station and were confined to small patches of the stopover areas. This is in accordance with hypothesis 3, and such differences occurred more often in Blue Tits than in Great Tits (Tables 3 and 4). But usually the composition of age and sex classes was similar at both catching localities operating at one station, even when a small sample of birds was caught (see 1980 for the Great Tit, Fig. 2). So we can conclude that the different assemblages of tits that were observed showed no tendency for birds of the same sex or age to form flocks (which was assumed by hypothesis 3). These different concentrations were more probably formed by birds originating exceptionally from different migratory groups, e.g. one of them migrating from a particularly long distance or displaced over the Baltic Sea by strongly unfavourable winds, as described by Lindholm (1978). Whatever the reasons for this phenomenon, the occurrence of different assemblages means that it is necessary (especially in Blue Tits) to catch a great number of individuals and that the mistnets must be set over a relatively large area to obtain precise data representative of the larger area. Population heterogeneity of migrating birds might be more intensely pronounced in species with a complex migration system, in which the migration flyways of different populations cross. It was found that in such species different migratory populations avoid mixing with each other (Busse, 1985; Bensch, 1999; Remisiewicz, 2002).

Very few direct ringing recoveries have been noted between stations MW and BK for both species of tits. Despite that, the observed age and sex ratios, especially for the Great Tit, were significantly similar at these stations for most years. This would confirm the assumption that the passage of Great Tits along the south-eastern Baltic coast is similar over large areas and that in each year its character is shaped by the same population and environmental factors (Nowakowski, 2002, 2003). That means data obtained for this species at one ringing station can be interpreted in a wide geographical scale as representative for the whole region. The few years when significant differences were detected in the age and sex ratios of Great Tits at the BK and MW stations can be linked to the unusual weather conditions mentioned earlier. Strong winds can displace large groups of Great Tits and Blue Tits over the Baltic Sea, or force some groups of the birds to choose an unusual migration route further inland (Lindholm, 1978; Alerstam, 1993; Nowakowski, 2003).

More differences between stations were recorded for the Blue Tit than for the Great Tit. Significant similarities between MW and BK occurred in about 30% of the years, but there were significant differences for almost the same number of years. So many years with different age and sex ratios cannot be explained only by atypical weather conditions, especially because more immatures were observed at BK for all the years in which the proportion of Blue Tits' age classes differed between these ringing stations. Moreover, an irruptive passage was observed at station BK in 2 years. In both these years the number of Blue Tits was more than 10 times higher than the mean yearly number of this species caught at this station. A high ratio (95%) of immatures was noted, which is typical of irruptive movements. For example Markovets, Sokolov (2002) stated that in the Coal Tit *Parus ater*, a typical irruptive species, the ratio of immatures among birds migrating during irruptions was between 94 and 99.9%. But at MW, as at stations further east in Lithuania, Estonia and Finland, the Blue Tit is a typical regular partial migrant (Nowakowski, Vähätalo, 2003, for MW also the present paper). In Western Europe the Blue Tit is known as an irruptive species (Winkler, 1974; van Balen, Speek, 1976; Lensink, 1990). Busse (1973) assumed that stations BK and MW catch, at least partially, different streams of tits moving through them, or the same streams but in different proportions. We think that station BK is in the border area for the Blue Tit. In some years its passage of migrants is affected by the same factors as on the south-eastern Baltic coast and the same migratory groups pass through it. In other years at this station populations of less regular migrants occur, influenced by conditions that cause irruptions. The presence of beech forests might be one of these conditions. Irruptions of tits are most often associated with the cycle of beech mast abundance (Alerstam, 1993). BK is the first ringing station in the zone of beech forests (Nowakowski, Vähätalo, 2003) that the tits encounter when moving from the north-east to the south-west (Hudec, 1983; Glutz von Blotzheim, Bauer, 1993). Perhaps irruptive populations are of local origin and their occurrence is connected to the cycles of beech mast at their breeding area. Such populations could have high breeding success (high proportion of young Blue Tits at BK not only in years of irruptions), which in some years leads to a high population density and hence to irruptive migrations.

The greatest variation between the catching localities of a station over a year was observed in the sex ratio of Blue Tits (Tables 3 and 4), though the sex ratio in this species at stations MW and BK was identical when many years of data were combined (Table 2). Sexing of Blue Tits is difficult and even highly experienced ringers sex some birds incorrectly (Busse, 1984; Svensson, 1992). These difficulties do not occur in sexing the Great Tit and in determining the age of both species. If at least some of the differences were an effect of mistakes in sexing and the varying experience of the ringers, the sex ratios in Blue Tits caught at the different localities might be even more similar than shown by this study. This seems probable because, in contrast to Blue Tits, the sex ratios of Great Tits showed an exceptionally low variation between stations and localities in the same year.

The differences in the composition of age and sex classes between migrating Great Tits and Blue Tits revealed in this paper did not exceed 3%. This result was, however, affected by results of the BK station, where Blue Tits, as opposed to Great Tits, tend to irrupt. In the area where both species are regular partial migrants, such as around the station MW (Nowakowski, Vähätalo, 2003), differences in the composition of age and sex classes did not exceed 1%. The Great Tit and the Blue Tit co-habit over most of Europe and occupy similar ecological niches, have a similar breeding biology (Cramp, Perrins, 1993) and their wings have similar flight properties (see figures in Jenni, Winkler (1994)) and thus their similar pattern of migration (see Ulfstrand (1962); Berhtold (1993) and Nowakowski, Chruściel (2004)) is not surprising.

Acknowledgements

This study was financially supported by the Polish Biodiversity Information Network (PBIN/KSIB) – a participant of Global Biodiversity Information Facility (GBIF).

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Ekológia (Bratislava) Vol. 32, No. 2, p. 186–196, 2013
doi:10.2478/eko-2013-0016

IDENTIFICATION OF SEASON-DEPENDENT RELATIONSHIPS BETWEEN SPECTRAL VEGETATION INDICES AND ABOVEGROUND PHYTOMASS IN ALPINE GRASSLAND BY USING FIELD SPECTROSCOPY

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Abstract

Halabuk A., Gerhátová K., Kohút F., Ponecová Z., Mojses M.: Identification of season-dependent relationships between spectral vegetation indices and aboveground phytomass in alpine grassland by using field spectroscopy. Ekológia (Bratislava), Vol. 32, No. 2, p. 186–196, 2013.

Spectral characteristics of alpine grasslands across the vegetation season (from May to September) are presented. The results are based on three year field spectroscopy monitoring of acid, nutrient poor grasslands at Kráľova hoľa research site, Low Tatras, Slovakia. Relationships between commonly used spectral vegetation indices (VIs) and field-based estimation of aboveground green phytomass (AGB) were analysed. Finally, season-dependent regression models were created in order to allow spatially extensive non-destructive monitoring of AGB. Spatial–temporal dynamics of background and standing litter markedly affect seasonal variations of relationships between VIs and AGB and predictability of the regression models. Because of a high proportion of litter during the whole season, this was a plant water–sensitive normalized difference water index (NDWI), which dominates as the predictive variable in the regression models across the whole season; except June, where chlorophyll absorption sensitive in normalized difference vegetation index (NDVI) performed the best (R^2 = 0.57; rel. RMSE = 34%). However, the accuracy of the models was quite low (May: R^2 = 0.45; rel. RMSE = 49%; July: R^2 = 0.47; rel. RMSE = 26%; August: R^2 = 0.13; rel. RMSE = 31%; September: R^2 = 0.53; rel. RMSE = 40%).

Key words: alpine meadows, biomass, Tatra Mts, cropscan.

Introduction

Knowledge on spatial–temporal information of biomass distribution across different ecosystems has represented a major topic of ecosystem research for many years. Recently, permanent monitoring of aboveground biomass across the scales has been emphasized in order to obtain accurate estimates of carbon stocks (Running et al., 1999). Alpine grasslands represent natural and sensitive ecosystems, which make them a suitable candidate for climate change impact research (Kanka et al., 2005; Boltižiar, 2001; Hreško et al., 2012). However, in experimental and long-term configuration of the research, destructive techniques may substantially affect the vegetation which can lead to misinterpretation of the studied factor (e.g. warming) under consideration. In this paper we analysed a non-destructive method for monitoring green aboveground biomass (AGB) in the alpine grassland. A seasonal development of AGB can serve as a robust surrogate for net primary production (Scurlock et al., 2002) and represents key indicator of ecosystem response to environmental and climate change. However, a demanding nature of field work in the alpine grasslands makes spatial estimation of AGB by standard destructive techniques very difficult and ineffective. Field spectroscopy has been used for many years for estimation of AGB (Milton et al., 2009). In particular, various spectral vegetation indices (VIs) that are sensitive for specific biophysical and biochemical characteristics of vegetation (Ollinger, 2011) became very popular for rapid estimation of AGB. The hope for an up-scale of this approach by using satellite sensors has even more accelerated usage of the spectral vegetation indices. In this regard, field spectroscopy also plays a crucial role in the field validation of the satellite-based estimations of AGB (Milton et al., 2009).

Many examples exist that prove the suitability of VIs as measures of production in arctic tundra (Boelman et al., 2005), alpine grasslands (Shen et al., 2008) or mountain meadows (Vescovo, Gianelle, 2008). However, due to the great importance of arctic vegetation for global carbon balance, there are many more reports and studies from arctic vegetation than from alpine grasslands in the mountains. On the other hand, there are also many studies that document weak relationship between VIs and grassland AGB (e.g. Riedel et al., 2005; Chen et al., 2009; Psomas et al., 2011), which is besides complicated canopy structure often explained by negative effect of standing litter on linear response of VIs on green vegetation. Van Leeuwen, Huete (1996) reviewed many examples where VIs predicting power of regression models between VIs and AGB decreased due to background and standing litter. In fact, as a result of the short vegetation season and harsh climate, alpine grasslands represent a mixture of background (at the beginning of the season) and standing litter (progressively emerging from the mid season), which can substantially influence the suitability of VIs for AGB estimation. This might also be the reason why the seasonal effect on VIs vs. AGB relationship is well known and documented (Riedel et al., 2005; Fava et al., 2009).

In any case, based on the results from a study in arctic tundra, Hope et al. (1993) stated that the relationship between biophysical properties and spectral reflectance must be approached with caution because it may be unstable across a growing season due to vegetation phenology and background conditions. This proves the fact that empirical relations of VIs and AGB are markedly site specific and season dependent (Malenovský et al., 2009). Therefore, it is crucial to evaluate the performance of vegetation indices for many case studies in different vegetation types because this helps explain the diversity and discrepancy of studies and the continued need for further exploration in an attempt to establish common protocols and baseline information related to biophysical remote sensing within and between biomes (Leprieur, 2000; Laidler, Treitz, 2003).

The main motivation of our research is the development of non-destructive approach for monitoring of seasonal development of AGB in alpine grasslands. In this paper, we analyse the suitability of commonly used VIs for estimation of alpine grassland AGB. Particularly, we report basic spectral characteristics of the alpine grasslands across the vegetation season and season-specific relationships of AGB with VIs resulting in season-dependent regression models.

Study area and methods

The research was localized in the natural alpine grasslands at the Mt. Kráľová hoľa research site (48°53´, 20°07´) at elevation of 1840 a.s.l. (Fig. 1). The grasslands at the research site belong to plant communities on acid substrates and shallow soils of the alliance *Juncion trifidi* Krajina 1933 represented by *Oreochloa disticha, Festuca supina, Juncus trifidus, Carex nigra, Campanula alpina, Vaccinium vitis-idaea, Vaccinium myrtillus, Avenella flexuosa, Cetraria islandica, Cladonia sp. and Polytrichum sp*. More detailed vegetation characteristics can be found in Barančok, Krajčí (2009). The mean annual temperature is 2°C and mean annual precipitation totals is 1200 mm (Faško, Šťastný, 2002).

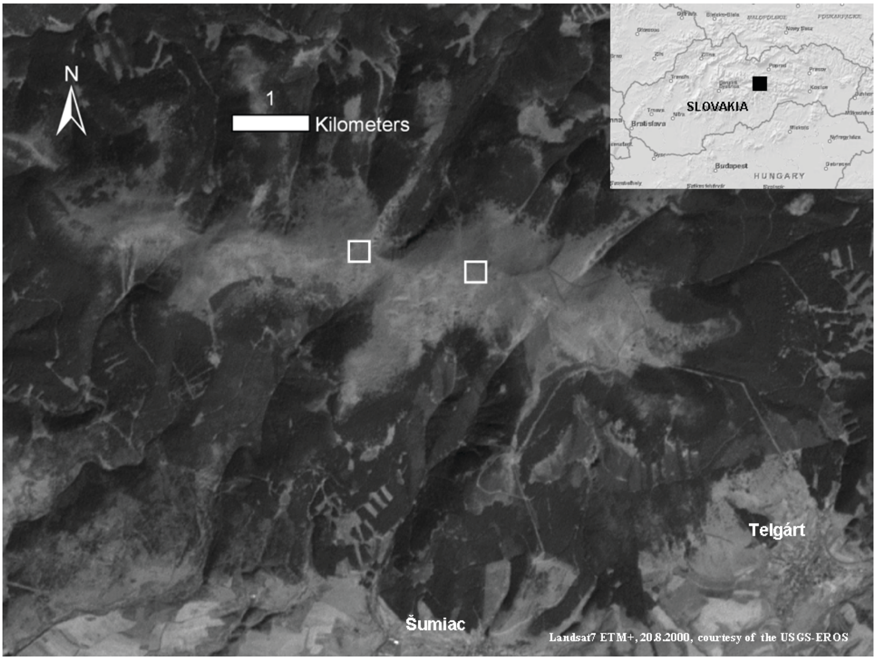

Fig. 1. Study site and sampling blocks.

A Cropscan 16 band multispectral field-portable radiometer (Cropscan, Inc., 2012) was used for field spectroscopy monitoring. Sixteen bands in radiometer were used in order to correspond to commonly used sensors such as Landsat TM5, MODIS and the planned Sentinel2 (Table 1). Cropscan contains upward- and downward--facing sensors in order to measure both incoming and reflected radiation, nearly simultaneously, which allows for useful reflectance readings in lightly cloudy conditions down to about 300 W m^{-2} incident irradiance (Cropscan, Inc., 2012). Sensors that measure reflected light have a 28° field of view, which means that sampling plots (30 x 30 cm) were scanned at 70 cm height at nadir position in order to reflect the canopy under consideration.

Field spectroscopy measurements were done regularly, together with field-based biomass sampling during the three year research from May 2010 to September 2012. Only the measurements that meet the strict criteria, namely scanning in nearly cloud-free condition and near-solar noon, were used in later analyses in order to minimize bidirectional effects on reflectance measures due to variations of illumination angles. We need to notice that the specific high mountain climate (e.g. high air humidity and scattered low clouds) did not allow strict regularity

Table 1. Filter bands used in 16 band multispectral radiometer CropScan.

Label	CWL[1] (nm)	BW[2] (nm)
b860	860	10
b610	610	10.3
b710	710	12.4
b1240	1240	11.6
b1540	1540	15.1
b1650	1650	200
b485	485	90
b561	560	80
b661	660	60
b830	830	140
b460	460	6.8
b560	560	9.4
b810	810	11.4
b760	760	10
b510	510	10
b660	660	11.6

[1] centre wavelength
[2] band width

of spectroscopy measurements, for example, every 14 days. Therefore, all the measurements from the whole three year period were aggregated to a monthly base.

Based on the spectral reflectance values, four commonly used VIs were calculated for their specific sensitivity to chlorophyll content: normalized difference vegetation index (NDVI; Rouse, 1974), green normalized difference vegetation index (GNDVI; Gitelson et al., 1996), red edge spectral parameter (RESP; Vogelmann et al., 1993); plant canopy structure: enhanced vegetation index (EVI; Huete et al., 2002); and water in plant tissue: normalized difference water index (NDWI; Gao, 1996). All the equations for the calculation of VIs are listed in the Table 2.

A standard destructive method for aboveground biomass estimation using 30*30 cm quadrates was used. Vascular plants were carefully clipped just above the soil surface with razor blade. Two research blocks approx. 800 m from each other, with dimensions approx. 50*50 m were used for the monitoring. Each research block was sampled by 12 randomly localized quadrates, that is 24 quadrates in total for the one date. Plant material was sorted out immediately in the laboratory in order to separate green phytomass and necromass. Finally, plant material was oven-dried at 75°C for 48 h and weighed.

Table 2. Spectral vegetation indices used in the study.

Vegetation index	Equation	References
Normalized difference vegetation index (NDVI)	NDVI = (b830 - b661)/(b830 + b661)	Rouse et al., 1974
Normalized difference water index (NDWI)	NDWI=(b860 - b1240)/(b860 + b1240)	Gao, 1996
Enhanced vegetation index	$2.5 \times \frac{(b860 - b660)}{(b860 + 6 \times b660 - 7.5 \times b460 + 1)}$	Huete et al., 2002
Green normalized difference vegetation index (GNDVI)	GNDVI=(b860 - b560)/(b860 + b560)	Gitelson et al.,1996
Red-edge spectral parameter (RESP)	RESP=b760/b710	Vogelmann et al., 1993

Pearson correlation coefficient R was used for assessment of relationships between VIs and AGB. Linear regression using step wise selection of predicting variables was used for the whole period and respective months. Coefficient of determination R^2, root mean square error (RMSE) based on unstandardized residuals, and relative RMSE (proportion of RMSE to respective mean values of dependent variable) were used as a measure of accuracy of the models. All statistical analyses were done using Statistica v.9 software (StatSoft, Inc., 2009)

Results

Seasonal development of AGB in alpine grasslands reaches its maximum in July; spatial variability of AGB is the highest in May and decreasing simultaneously with growth of the green vegetation until August (Fig. 2). A substantial proportion of non-photosynthetically active vegetation (NPV) occurs during the whole season. It is highest in May, lowest in July and progressively increases until September following the development of standing litter. Thus, the proportion of the NPV reflects the two simultaneous processes – decomposition of background litter from the previous year and formation of the standing litter from the peak season.

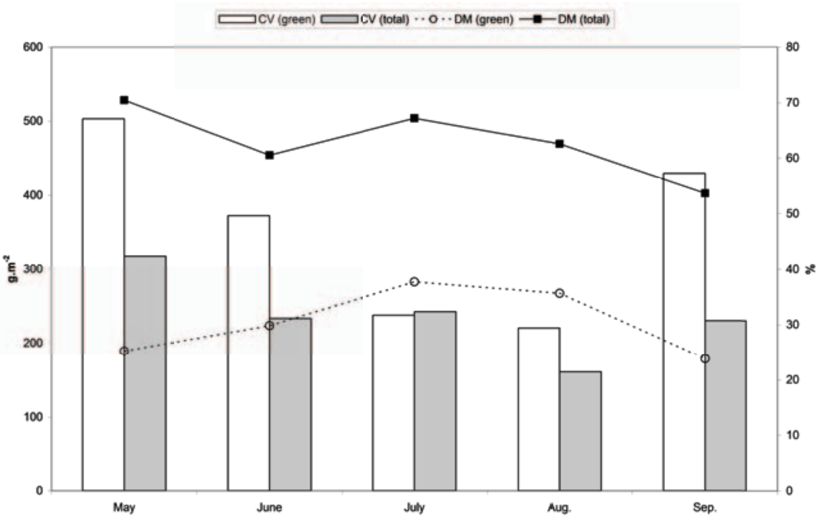

Fig. 2. Seasonal development of green phytomass and total aboveground phytomass (dry matter DM in g m^{-2}). Bars represent coefficients of variation (CV in %).

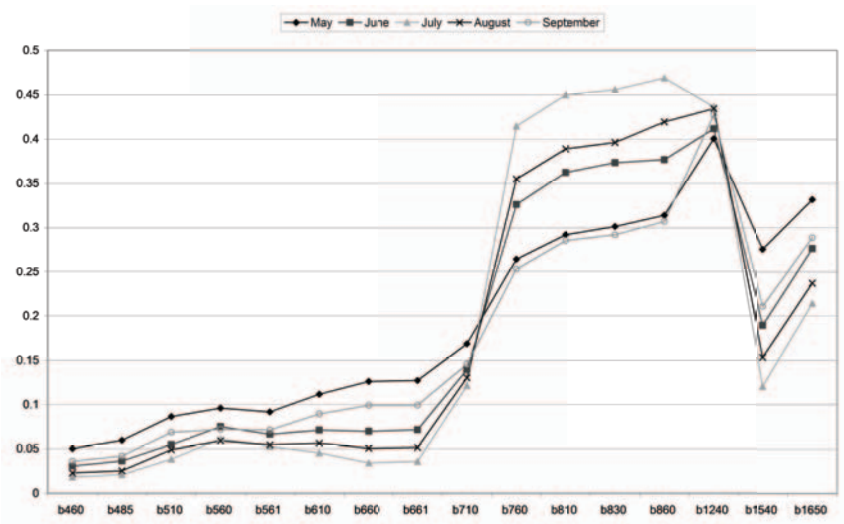

Fig. 3. Spectral characteristic (in reflectance units 0–1) in 16 spectral bands (see Table 1 for band width information) across the season.

The spectral characteristics of alpine grassland varied substantially across the season (Fig. 3). There is consistent difference in the chlorophyll absorption region (RED – 660 nm), being the highest in July (the seasonal peak) and the lowest in May, which corresponds to the fraction of green phytomass in the stands (Fig. 2). In the near infrared region (NIR), where reflectance is driven mainly by scattering of incoming radiation, the far highest reflectance is visible in July followed by proportionally lower values in August and June (Fig. 3). The reflectance in the NIR region in May and September is about the same. The middle infrared region (MIR) is recognized as sensitive for plant water content since it has the low reflectance value where water absorption is high. This fact is identified in the 1540 and 1650 nm spectral region, having the lowest value in summer and the highest in early spring, which again follows the fraction of green vegetation development across the season (Fig. 2). Quite a divergent pattern was identified in the 1240 nm spectral region, which is discussed in the next section.

The development of seasonal temporal profiles of VIs generally corresponds to that of AGB. However, seasonal and spatial variability varies among the VIs as they are sensitive to slightly different canopy characteristics (Fig. 4). The highest amplitude is visible in the EVI and NDVI series. By far, the highest spatial variability is visible in NDWI. In addition, the well-known saturation of the NDVI and GNDVI is visible in July and August compared to EVI and RESP.

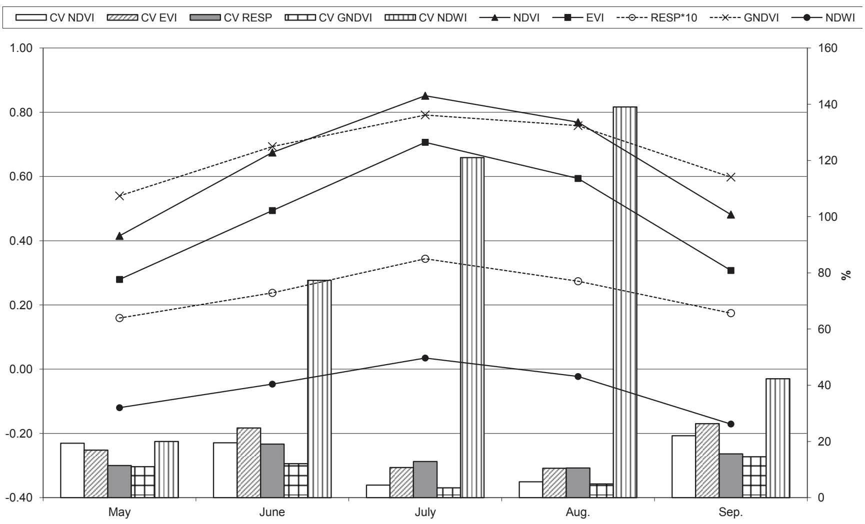

Fig. 4. Seasonal profile of spectral vegetation indices (unitless index from -1 to 1). Bars represent coefficients of variation (CV in %).

When the whole season is considered, all the VIs correlate significantly with the AGB, with the highest rate in NDWI (Table 3). The seasonal variation of the relationships is quite diverse (Table 3). Only the NDWI correlates with AGB significantly in all months having the highest rate in May. Other VIs exert similar correlations with AGB, having the only significant correlations in June and no significant correlations in August and September. Except the NDWI, only NDVI shows significant correlation with AGB in July.

The coefficient of determination and RMSE of the season-dependent linear regression models are reported in Table 4. Except for the June model, where chlorophyll and structural sensitive VIs, namely NDVI, GNDVI and EVI, were selected, NDWI was selected as the

T a b l e 3. Pearson correlation coefficients between spectral vegetation indices and green aboveground phytomass.

Month	EVI	NDWI	GNDVI	NDVI	RESP	N
May	0.23	0.67**	0.17	0.28	0.22	32
June	0.48*	0.51*	0.46*	0.55*	0.46*	28
July	0.29	0.47**	0.08	0.34*	0.03	43
August	0.03	0.37*	-0.25	-0.16	-0.08	36
September	0.23	0.58**	-0.18	0.01	0.1	24
ALL	0.45**	0.53**	0.29**	0.39**	0.35**	199

* correlation significant at 0.05 level
** correlation significant at 0.01 level

T a b l e 4. Selected variables, coefficients of determination and RMSE of the linear regression models.

Model	Predictors	R	R^2	RMSE	rel. RMSE
May	NDWI	0.67	0.45	8.33	48.94
June	NDVI. GNDVI. EVI	0.76	0.57	6.94	34.46
July	NDWI. RESP. NDVI	0.69	0.47	6.55	25.75
Aug.	NDWI	0.36	0.13	7.33	30.46
Sep.	NDWI. GNDVI. EVI	0.73	0.53	6.41	39.83

T a b l e 5. Estimated coefficients of the season-dependent regression models.

Model		Unstandardized coefficients	Standardized coefficients	*t*	Sig.	Partial Corr.
May	(Constant)	54.69		6.93	0.00	
	NDWI	315.06	0.67	4.87	0.00	0.67
June	(Constant)	52.02		2.38	0.03	
	NDVI	376.08	4.57	4.38	0.00	0.67
	GNDVI	-292.44	-2.26	-3.57	0.00	-0.59
	EVI	-166.26	-1.88	-3.07	0.01	-0.53
July	(Constant)	-94.37		-2.17	0.04	
	NDWI	84.20	0.39	2.25	0.03	0.34
	RESP	-201.49	-0.98	-4.24	0.00	-0.56
	NDVI	217.01	0.90	3.30	0.00	0.47
Aug.	(Constant)	25.52		15.89	0.00	
	NDWI	89.32	0.36	2.15	0.04	0.36
Sep.	(Constant)	50.29		6.78	0.00	
	NDWI	58.69	0.45	3.63	0.00	0.48
	GNDVI	-66.93	-0.62	-4.21	0.00	-0.53
	EVI	50.06	0.43	2.58	0.01	0.36
ALL	(Constant)	34.94		7.98	0.00	
	NDWI	77.60	0.69	5.68	0.00	0.39
	RESP	-97.99	-0.75	-3.24	0.00	-0.23
	EVI	29.13	0.53	2.15	0.03	0.16

predictive variable for all the models. The highest R^2 was obtained in the June model, and the lowest in August, the lowest relative error was again in the July model. All the coefficient estimates and partial correlation of the respective terms are listed in Table 5. The relative influence of selected predictive VIs is discussed in the later session.

Discussion

Spectral characteristics across the season varied substantially having the great NIR vs. RED contrast in July, which corresponds to the peak biomass season in alpine grassland. Seasonal variance of spectral characteristics in grasslands is obvious and was recognized by Fava et al. (2009) and Rundquist (2002) and may indicate specific phenology of the respective vegetation, management practices or litter dynamics. In our case this was mainly litter dynamics, which mainly drove seasonal variability of vegetation spectral response. Similar reflectance in the green region in June and September followed by contrast reflectance in the red region might be attributed to higher photosynthetic activity and chlorophyll content in June or proportionally higher negative effect of standing litter in canopy mixture in September than that of background litter in June. The NIR region can respond to canopy structural characteristics, such as LAI which might closely correlate to total biomass in the case of prevailing grassy species. In this respect, the similar spectral response in May and September might be caused by the fact that in May lower green photosynthetically active vegetation is present, but proportionally higher values of NPV phytomass (Fig. 2) can contribute to leaf reflectance in NIR. Another interesting divergence is visible in MIR 1240 nm spectral region compared to that of 1540 nm and 1650 nm. Bearing in mind the great fraction of NPV in May and June compared to that in September, we suggest that MIR 1650 nm spectral region is more sensitive to NPV, whereas 1240 nm spectral region is sensitive to plant water.

In general, taking into account a whole season from May to September, NDWI performed at the highest rate in the regression models. When the whole season is considered, the predictive power of VIs substantially decreased, which stressed the fact that season-dependent relationships should be considered, mainly in the native grasslands where spatial–temporal variability of litter is high (Rundquist, 2002). Our results proved the substantial seasonal effect on the relationships between VIs and AGB. In our case this seasonal effect strongly corresponds to NPV seasonal dynamics.

A proportion of background litter in early spring (May) is substantially higher than green phytomass (Fig. 2), which might cause the fact that NDWI was selected as predictor for regression model in May. Vescovo, Gianelle (2008) and Psomas et al. (2011) report the higher predictive power of the regression models that include MIR wavelengths and stated that mainly sensitivity to water in plant tissue might be better for prediction of green phytomass in natural grasslands. Anyway the great amounts and spatial variability of background litter, which is undecomposed from previous season, might cause the relatively high r_rmse (48%). Riedel et al. (2005) showed the R^2 for relationships between total live phytomass and NDVI in early spring is substantially lower than those of the early summer which might be caused by the similar effect of background litter in early spring and overgrown green phytomass in early summer.

The strong fast development of green biomass in June is well reflected by chlorophyll-sensitive indices such as NDVI, EVI and GNDVI. In early spring, background litter on the soil surface is obscured by green vegetation, thus green vegetation can be easily detected by the sensors of the radiometer. Many authors reported similar results stating that it is exactly at the beginning of the growing season when the strongest relationships between VIs and AGB can be found in natural grasslands (Psomas et al., 2011; Rundquist, 2002). However, the exact date of the highest relationships is vegetation and site specific, as the specific vegetation type may have different canopy structure and phenology of dominant species can vary substantially. This was proved by Boeleman et al. (2005) as they report substantially different values of R^2 for regression models between NDVI and AGB in wet sedge tundra ($R^2 = 0.84$) and tussock tundra ($R^2 = 0.56$). Similarly, values of R^2 for the regression model between NDVI and AGB in five major grassland types in Tibetan Plato ranges from 0.57 to 0.86 (Shen et al., 2008).

We think that the highest accuracy of the June model in our study is because of a maximum photosynthetic activity at the beginning of the season (June) and relatively simple double layer design of the grassland, meaning that green phytomass is the upper layer and is not mixed with any standing litter as it is in the late season. However, background litter on the soil surface with high spatial variability still affects the performance of VIs, which results in relatively high r_rmse.

Late July is regarded as the peak biomass season in alpine grasslands, thus estimation of AGB at peak season is thought to be crucial for total approximation of production. Therefore many authors report only the VIs–AGB relationships from this period. In our case, as the season proceeds, standing litter appeared progressively till the late season when it dominates the stands. In this respect, inclusion of NDWI in the models from July reflects the standing litter and sensitivity to plant water dominates the regression models until the late season. Similarly, Kushida et al. (2009) report from sedge-shrub tundra R^2 of linear estimation of the green phytomass and NDVI of 0.39, whereas by using NDII (the same as NDWI, while using MIR at 1650 nm spectral region instead of 1240 nm) they get R^2 of 0.63. Although not substantially, RESP was included in the regression model for July, which might prove the suitability of RED-EDGE based indices in prediction of AGB when vegetation greenness is saturated (Mutanga, Skidmore, 2004) as was later proved by Chen et al. (2009) for alpine grasslands with high canopy cover, although they also report relatively weak relationship between VIs and AGB with R^2 ranges from 0.13 to 0.3. As a result in the peak biomass season, NDWI, RESP and NDVI predict the best AGB, although the reason for negative partial correlation of RESP needs to be better explored in further ecophysiological research at the site.

The lowest relationship between AGB and VIs was found in August, which we think was mainly due to occurrence of standing litter, which make the canopy structure complicated having the variable NPV to PV ratio. Similarly, Riedel et al. (2005) reported substantially lower predictive power of August regression model (R^2 approx. 0.12) compared to that of July (R^2 approx. 0.6). In our case, the September regression model performed better compared to that of August. We think that this is due to the simpler canopy structure representing by standing litter that dominates the upper level of the canopy, which again allows predictability of AGB by NDWI.

Conclusion

To conclude, spectral characteristics of the alpine grasslands varied substantially in spatial and seasonal terms. The main reason for this is mainly a spatial–temporal variation of background litter in the beginning of the season and progressing development of standing litter from august to late season. The higher proportions of the litter across the whole season results in suitability of VIs, which include MIR band, that are sensitive to water in plant tissues. Even though predictability of the models was relatively low, bearing in mind the difficulties of the field work in the alpine environment, we think that these models may be used for non-destructive estimation of AGB in experimental research (June model) or in monitoring of AGB (July model) in alpine grasslands. However, more research using field spectroscopy in alpine grasslands is needed and this should include another vegetation types in order to approach the common protocols for monitoring of alpine grasslands with respect to their response to changing environment. Field spectroscopy using broadband indices should be considered in this effort because of upcoming satellite missions such as Sentinels2, which bring hope for up-scaling of the field-based evidence to broader scales.

Acknowledgements

This work was fully supported by the Scientific Grant Agency of the Ministry of Education of Slovak Republic and the Academy of Sciences under Grant No. 2/0217/09.

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Ekológia (Bratislava) Vol. 32, No. 2, p. 197–210, 2013
doi:10.2478/eko-2013-0017

DEVELOPMENT OF SOIL PARAMETERS AND CHANGING LANDSCAPE STRUCTURE IN CONDITIONS OF COLD MOUNTAIN CLIMATE (CASE STUDY LIPTOVSKÁ TEPLIČKA)

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Abstract

Fazekašová D., Boltižiar M., Bobuľská L., Kotorová D., Hecl J., Krnáčová Z.: Development of soil parameters and changing landscape structure in conditions of cold mountain climate (case study Liptovská Teplička). Ekológia (Bratislava), Vol. 32, No. 2, p. 197–210, 2013.

Soil physical, chemical and biological properties and the content of heavy metals were investigated between 1997 and 2010 and changing landscape structure was evaluated for years 1948–2010 under production conditions in the investigated area Liptovská Teplička (48° 57´ N; 20° 05´ E), situated in the marginal region of north-eastern Slovakia. Research showed that soil physical properties get adjusted after a long-term application of ecological farming system and the measured values were stabilised. High doses of organic fertilizers had positive effect on soil fertility, and thus indirectly on maintaining soil pH, available nutrients content and accumulation of humus in soil. The values of soil enzymes activities changed minimally during the research period. At the same time, it was proven that increasing the content of soil organic matter promotes natural protection of soil enzymes. This study underscores the importance of long-term, quantitative soil monitoring in determining the changes in agricultural land and ecosystem processes over time. Statistically significant effect of experimental year on all observed soil parameters was confirmed by analysis of variance. Effect of experimental locality, with the exception of pH/$CaCl_2$, C_{ox} and N_{anorg}, on other soil parameters was also statistically significant. This area represents a specific mountain grassland-arable landscape with conservation of traditional agriculture. The results of this paper also analyse landscape structure changes by using the historical maps and aerial photographs of the past 160 years.

Key words: ecological farming system, chemical properties, physical properties, soil enzymes, heavy metals, landscape structure changes.

Introduction

Agricultural activities are realised in landscape and affect natural resources. A rational usage of renewable and non-renewable resources which are not retrieved in real time is an essential precondition. The farming system is the most widespread environmental technology with its positive and negative consequences. It utilises essential natural resources and, at the same time, influences other natural environments. Soil parameters indicate the state of soil ecosystem characteristics, which especially reflect production, buffering, filter and other soil functions. From this view, the structure of soil profile (the soil class), soil type, soil depth, skeletal nature, the content and quality of humus substances, accessible nutrient supply, soil reaction, the content of foreign substances in soil and soil edaphon seem to be of highest importance. Maintenance of the environmental quality and not exceeding the pollution limits are the most important indicators. Soil quality is significantly affected by the physical, chemical, biological and biochemical properties that are sensitive to changes in environment and soil management. Pollution of the soil environment with heavy metals negatively influences the whole ecosystem. The soil parameters such as pH, organic matter, nitrogen content, nutrients availability, texture, bulk density, porosity and soil enzyme activities can influence the behaviour of metals in soil (Fazekašová, 2012; Beesley et al., 2010). Ecological stress and other environmental changes in soil ecosystem can be judged in advance through some sensitive and warning indicators. These indicators include biological and biochemical properties in soil, including microbial quotient, nitrogen mineralization and the activities of soil enzymes (Nannipieri et al., 2003; Sarkar et al., 2009).

This area is a specific mountain grassland-arable landscape with conservation of traditional agriculture. Historical structures of this area represent extensive cultivated fields, meadows and pastures, which have not been affected by agriculture collectivization and are characteristic by the following features: small-scale structure of the plot and original forms of anthropogenic relief. It is from this point of view that we have also focused to analyse the influences to this unique landscape structure changes by using the historical maps and aerial photographs of the past 160 years.

The paper presents the results of long-term monitoring and impact assessment of ecological farming system on selected soil parameter developments and changing of landscape structure in less favourable soil-climatic conditions.

Material and methods

The research project was carried out during the years 1997–2000 and 2008–2010 under production conditions in the investigated area Liptovská Teplička (48° 57´ N; 20° 05´ E), situated in the marginal region of north-eastern Slovakia. The ecological farming system has been applied here since 1996 (Hanzes et al., 2006, 2011).

The area of Liptovská Teplička is situated in the Low Tatras National Park at an altitude ranging from 846 to 1492 m a.s.l. In terms of geomorphological division, it is a part of the sub-assemblies of the Kráľovohoľské Mountains (Michaeli, Ivanová, 2005). The whole area is situated in the mild zone with sum of average daily temperatures above 10°C ranging from 1600 to 2000 mm and average precipitation of 700–1200 mm (Fig. 1).

In the current crop structure, cereal acreage represents 33.3%, potatoes 16–18% and fodder crops 49.8%. Crop rotation is as follows: perennial fodder (clover mixture), winter crops (winter wheat, winter rye, triticale and winter barley), root crops (potatoes), spring crops (spring barley, oats) and annual mixture (oats pea, peas, ryegrass). Arable land is fertilized with manure dosage of about 30 t ha^{-1} once in two years (Fazekašová et al., 2011, 2012).

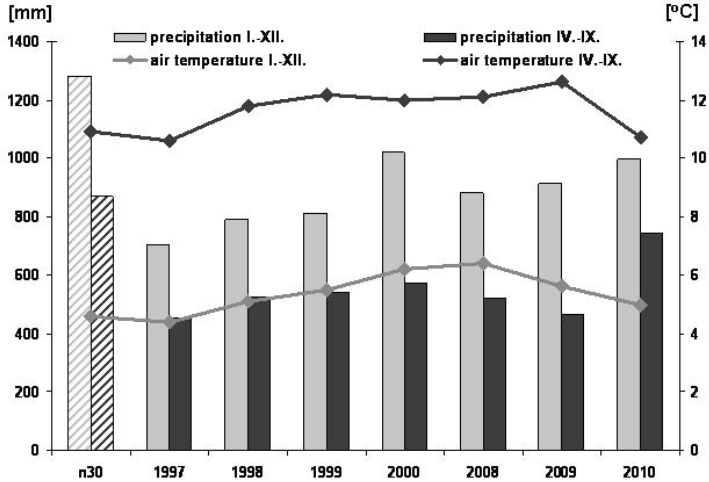


Fig. 1. The course of average air temperatures (°C) and sum of precipitation (mm) during observed period (n30 = long time normal).

Soil samples for physical, chemical and biological properties and heavy metals content determination were sampled in spring time in connected stand on five permanent research sites. Soil bulk density and soil porosity were studied and evaluated as the general physical properties in Kopecky physical cylinder with a capacity of 100 cm^3 (Fiala et al., 1999). From the chemical soil characteristics, we monitored and evaluated soil pH in 1M $CaCl_2$ solution an organic nitrogen, available phosphorus, potassium and magnesium with Mehlich III and organic carbon content (Fiala et al., 1999). Available heavy metal content (Cd, Ni and Pb) in the soil samples were determinated in 2M HNO_3 solution using atomic absorption spectrophotometer (Matúšková, Vojtáš, 2005). Monitored biological soil characteristics were as follows: activity of acid and alkaline phosphatase (Grejtovský, 1991) and urease (Chaziev, 1976).

For the analysis of landscape structure changes we used historical military maps at the scales of 1:28,886 (year 1826) and orthophotos from 1949 (panchromatic) and 2006 (real colors) were used as base layers. For the identification of landscape structure elements a modified legend was used. They were identified through manual vectorisation ('on screen' method) of historical maps and orthophotos by the GIS software – ArcGIS 10.2.

Obtained data were tested by mathematical–statistical methods from which analysis of variance and regression analysis were used (the Statgraphics software package).

Results and discussion

Development of soil parameters

The variety topography, mineral substrates and considerable humidity area necessitated the creation and development of a specific spectrum of soils. On carbonate minerals – dolomites and limestones – moderate to strong skeletal Rendzic Leptosols were created. In higher altitude and higher humidity they alter to Cambic Rendzic Leptosols. The occurrence of these minerals binds on south part of cadastral area of Liptovská Teplička on large complex of Ramsar dolomitic limestones. Mineral-rich, non-carbonate substrates such as basalts, andesites and marl slate make the part of moderate humic and medium depth of Cambisols. These Cambisols can be found in northern part of territory. This Haplic Cambisols complex is used as small terraced fields near built-up area of Liptovská Teplička village. Poor mineral rocks such as light grey conglomerates, variegated sandstone, siltstones and slate make the formation Haplic and Stagnic Cambisols. Valleys bottoms are constructed by fluvial sediments where a complex of Haplic and Gleyic Fluvisols was developed.

Physical parameters are specific characteristics of soil and their change occurs in adjusting of ecological conditions of the crops grown. Favourable physical parameters of soil are now becoming targets to which the management and protection of land is looking forward. The basic physical parameters of the soil are bulk density and total soil porosity (Kotorová, Šoltysová, 2011). On the basis of clay particles content and in accordance with Novák's classification scale (Fulajtár, 2006; Zaujec et al., 2009), soils in monitored sites are loamy–sandy soils, loamy soils and clayey–loamy soils (Fazekašová et al., 2011).

Bulk density as an integral value of the soil grain, humus content and anthropogenic impacts on soil should not increase over limits given for individual types of soil (Table 1).

T a b l e 1. Critical values of soil bulk density (t m^{-3}) and porosity (%) for different soil texture (Líška et al., 2008).

Soil texture	Sandy	Loamy sand	Sandy loam	Loam	Clayey loam and clay	Clay
Bulk density	≥1.70	≥1.60	≥1.55	≥1.45	≥1.40	≥1.35
Porosity	≤38	≤40	≤42	≤45	≤47	≤48

Long-term research has shown that ecological soil farming regulates bulk density of soil. The measured values of bulk density were in the range of 0.94 to 1.35 t m^{-3} (Fig. 2). During 1997–2009, there was a moderate decrease and values comparable to average figures for the given soil type and category according to Líška et al. (2008) were achieved (Table 1); except in 2010, when a mild increase in bulk density was measured. At the same time, this parameter proved to change under the influence of the water content and meteorological exposure (Kotorová et al., 2010). In 2010, in comparison to the previous years, the precipitations reached higher values (Fig. 1). General porosity is closely related to bulk density. From the total pore volume, this should not fall below 38% for sandy soil and below 48% for clayey-loamy soil (Líška et al., 2008). As seen from Fig. 2, the values show that, in the observed time frame, porosity levels ranged between 46.43 and 64.49%. Considering this parameter, optimum conditions were created for the growth of most arable crops, which are given by general porosity between 55 and 65% and 20 and 25% soil air content (Rode, 1969).

Soil pH is one of the important factors of soil fertility despite the fact that its values change dynamically depending on so-called internal and external factors. Factors including parent material, weathering and current agricultural practices influenced the pH of a soil change over time. It affects the availability of nutrients and how the nutrients react with each other. During the monitoring period the value varied minimally, and the average value of soil reaction, expressed as pH/$CaCl_2$, ranged between 5.1 and 7.2 (Fig. 3). This can be assigned to the ecological farming system because the physiologically acid mineral fertilizers were not applied, and the organic fertilizers (manure at the dosage 30 t ha^{-1} and Natural Harmony at

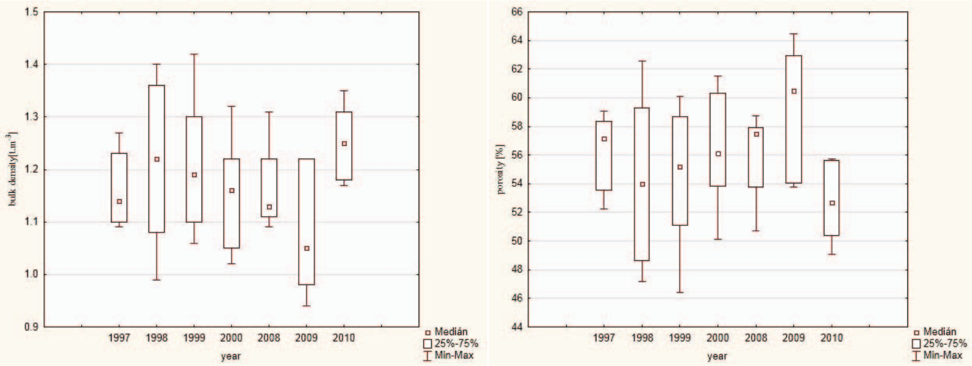


Fig. 2. Bulk density and porosity of soil on the studied area Liptovská Teplička in the years 1997–2010.

the dosage 3000 t ha^{-1}) were applied. Organic matter positively influences the buffering capacity of soil and thus the soil reaction was not reduced.

Particular attention should be paid to the adjustment of soil reaction on soil where the pH is below 5.5, because of the release of aluminium ions and their toxic effects on plants. For most crops, the soil reaction ranges 6.5 and this value provides favourable conditions for root nutrition and microbial activity. Organic matter content affects to maintain soil reaction. Despite the positive impact of ecological farming system to maintain soil acidity and organic matter content, it is necessary to continuously pay attention to soil reaction as soil is naturally acidified through acid atmospheric fallout as well as calcium uptake by plants. Humus content is a parameter that is liable to significant changes during longer periods of time. Application of high amounts of organic fertilizers had an effect on maintaining or slightly increasing humus content. The values of C_{ox} ranged from 2.16 to 3.92%, which on conversion to humus (conversion coefficient 1.724) are medium and good humic soils (Vilček et al., 2005). Our research confirmed suitability of the area for ecological farming and at the same time the positive influence of the applied system on humus balance in soil. There is a little probability that increasing of the total nitrogen content has a positive effect on the soil fertility (Bielek, 1998). This applies only for productive and highly productive soils. For the soils with low production capacity, to which the investigated area belongs, a reciprocal relationship between total nitrogen content and soil fertility is typical. Total nitrogen content in soil, 95 to 98% is bound in organic forms, fertility functions are conditioned to mechanisms of its accessibility to plants. It is mainly organic nitrogen mineralization, more specifically the part of mineralization, which prevails over carbon immobilization that relates to fertility. In the soil-ecological conditions of the investigated area, the nitrogen mineralization is less intensive (optimal temperature for intensive process is 28–30°C), therefore, the content of mineral, that is immediately available nitrogen, may not be high even at high levels of total nitrogen (Fig. 3). The assumption is that addition of high doses of organic fertilizer will increase the total nitrogen content, but growing legumes included in the crop rotation can increase the content of immediately available nitrogen. Phosphorus is firmly fixed in soil and its proportion is relatively stable and dependent on soil reaction values. The value of soil pH did not change significantly in the investigated area between 1997–2000 and 2008–2010, and the proportion of available phosphorus changed only minimally (Fig. 3). The proportion of potassium and magnesium was relatively stable during the research period (Fig. 3). Due to the grain structure of the soils (medium and heavy soils) these nutrients are bound to the soil particles and are not liable to soil washing in spite of high precipitation throughout the year.

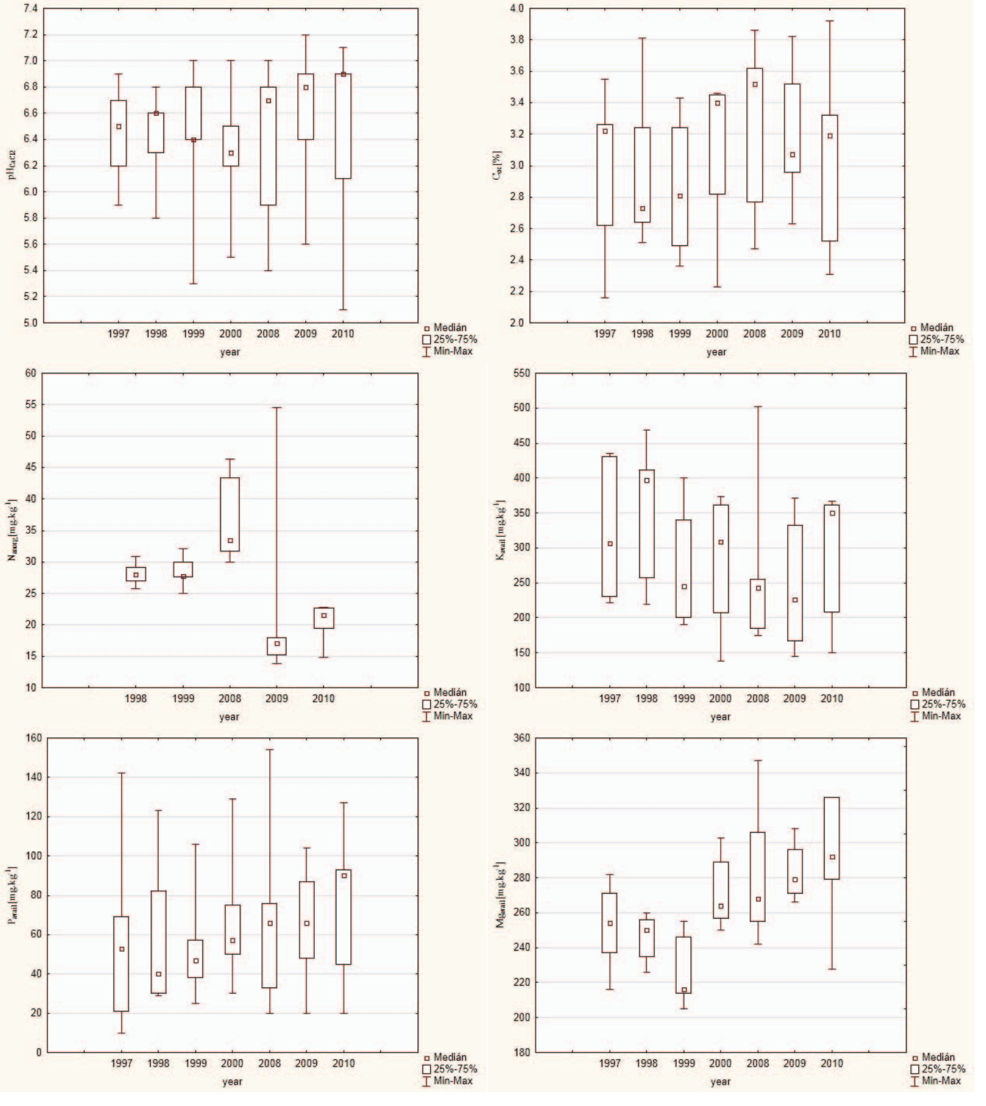
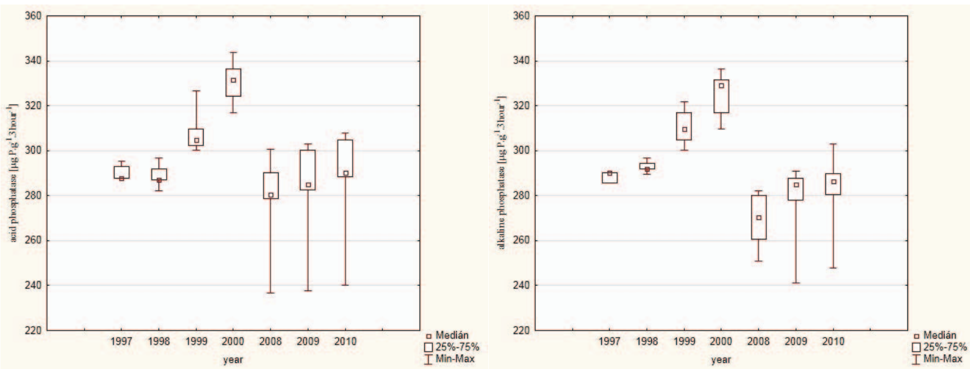


Fig. 3.Soil chemical parameters (pH, C_{ox}, $N_{anorg,}$ $K_{avail,}$ P_{avail}, Mg_{avail}) on the studied area Liptovská Teplička in the years 1997–2010.

Soil enzymes regulate the functioning of the ecosystem and play key biochemical functions in the overall process of organic matter decomposition in the soil system (Burns, 1983; Sinsabaugh et al., 1997). They are important in catalysing several important reactions necessary for the life processes of micro-organisms in soils and the stabilisation of soil structure, the decomposition of organic wastes, organic matter formation and nutrient cycling (Dick et al., 1994). There was minimum fluctuation in the measured values of soil enzyme activity in the observed period. The urease values ranged from 0.43 to 0.67 mg NH4^{+}-N.g^{-1}.24 h^{-1}, and the values of acidic and alkaline phosphatise between 236.8 and 336.5 μg P.g^{-1}.3 h^{-1} (Fig. 4). These are values typical for sparse-vegetation soils (Burns, 1978). At the same time, a higher activity of soil enzymes in lower temperatures was confirmed (the area is situated in a mild district with a sum of average daily temperatures above 10 °C, ranging from 1600 to 2000, and average precipitation between 700 and 1200 mm) and organic fertilisers and soil organic mass stimulate the activity of soil phosphatise and significantly enhance the protection of natural soil urease (Chaziev, 1976; Burns, 1978).



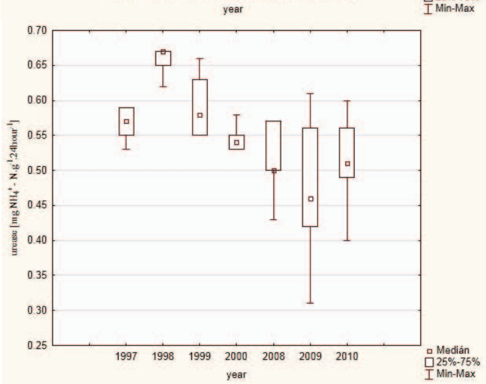
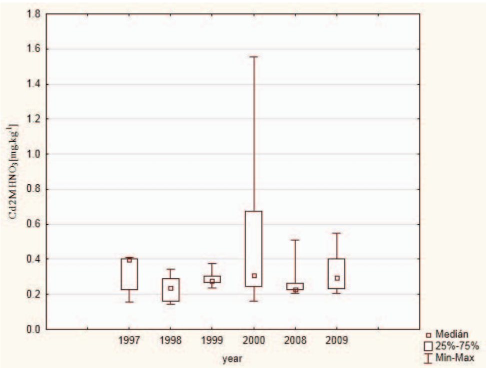
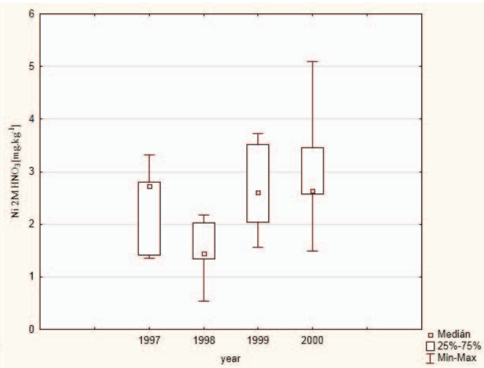


Fig. 4. Soil enzyme activity (acid phosphatase, alkaline phosphatase and urease) on the studied area Liptovská Teplička in the years 1997–2010.

Heavy metals as a large group of polluters are a serious problem in all components of the environment. Great numbers of these have considerable toxic effects. Toxicity of heavy metals varies; it decreases in the following order Hg>Cd>Ni>Pb>Cr and their influence is enhanced by their non-degradability. Soil is only presented as a passive acceptor of heavy metals; it becomes the source of polluting other components of the environment and the food chain. Changes in soil properties are responsible for the mobilisation of metals, especially pH, humus content and quality and the proportion of clay fraction (Barančíková, 1998). With regards to the above findings, the content of the following risk elements was observed in the conditions of sustainable use of soil: lead, cadmium and nickel (in the leachate 2M HNO_3) (Fig. 5). The evaluation showed that the content of dangerous elements in soil did not reach maximum permitted values for the Slovak Republic (Act No. 220/2004 Coll.) and the measured values corresponded with natural contents of the observed elements in soil and base rocks (Makovníková et al., 2006). At the same time, in ecological systems, no anthropogenic pollution by applying chemical substances and sediments in soil is present.





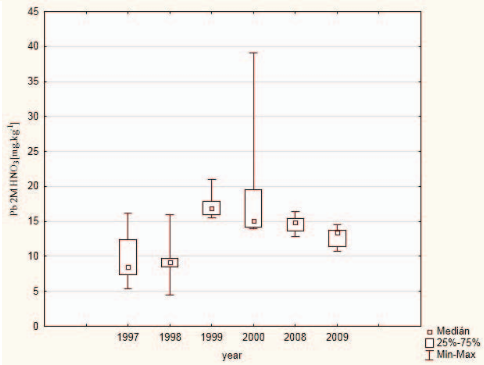


Fig. 5. Heavy metals content (lead, cadmium and nickel) on the studied area Liptovská Teplička in the years 1997–2009.

Statistically significant effect of experimental year on all observed soil parameters was confirmed by analysis of variance (Table 2). Effect of experimental locality, with the exception of pH/$CaCl_2$, C_{ox} and N_{anorg}, on other soil parameters was also statistically significant. Significant, statistical and statistically significant dependences between observed soil parameters are expressed in Table 3.

Landscape structure changes in the selected time horizons

Landscape structure changes were identified from historical military maps (1846) and historical and present aerial orthophotographs (years 1949 and 2010 processed in GIS. This approach is a typical standard method in this specific research (Olah, 2003a, b, 2009; Pucherová, 2004; Falťan, Bánovský, 2008; Falťan et al., 2009, 2011; Šolcová, 2012; Vojteková, 2013; Ivanová, 2013; Solár, 2012) Specific landscape structure of the study area represented the relatively stable territory with these following significant changes:

T a b l e 2. Variance analyses of physical, chemical and biological parameters.

Parameter	Min.	Max.	Mean	Standard error	P significance	Source of variability	d. f.	F-Ratio	P
bulk density ($t.m^{-3}$)	1.04	1.35	1.18	0.016347	++	year locality	6 4	8.33 28.39	++ ++
porosity (%)	49.15	60.56	55.52	0.617864	++	year locality	6 4	8.24 28.41	++ ++
$pH/CaCl_2$	5.77	7.13	6.41	0.083124	-	year locality	6 4	0.82 24.51	- ++
C_{ox} (%)	2.25	3.61	3.03	0.084802	-	year locality	6 4	1.46 23.99	- ++
N_{anorg} ($mg.kg^{-1}$)	16.76	40.50	27.52	1.698623	++	year locality	6 4	12.77 2.22	++ -
$P_{avai}l$ ($mg.kg^{-1}$)	19.97	127.88	64.63	3.494827	++	year locality	6 4	3.02 121.06	++ ++
K_{avail} ($mg.kg^{-1}$)	168.59	427.98	290.91	12.5772	++	year locality	6 4	5.87 43.46	++ ++
M_{gavail} ($mg.kg^{-1}$)	215.98	301.43	265.0	4.918103	++	year locality	6 4	17.52 3.73	++ ++
$Pb2MHNO_3$ ($mg.kg^{-1}$)	7.77	22.18	14.11	0.823555	++	year locality	6 4	12.30 22.01	++ ++
Cd 2M HNO_3 ($mg.kg^{-1}$)	0.129	0.697	0.343	0.037233	++	year locality	6 4	9.37 19.69	++ ++
Ni 2M HNO_3 ($mg.kg^{-1}$)	0.934	3.436	2.392	0.140375	++	year locality	6 4	24.08 25.20	++ ++
urease (mg NH_4^+ - $N.g^{-1}.24hour^{-1}$)	0.454	0.674	0.551	0.007954	++	year locality	6 4	44.07 33.12	++ ++
acid phosphatase (μg $P.g^{-1}.3hour^{-1}$)	271.23	306.77	294.91	2.65001	++	year locality	6 4	36.16 15.85	++ ++
alkaline phosphatase (μg $P.g^{-1}.3hour^{-1}$)	264.35	329.33	291.97	1.96567	++	year locality	6 4	75.50 16.39	++ ++

++P< 0.01 +P< 0.05

Landscape structure in 1846

The village Liptovská Teplička on the northern slopes of the Nízke Tatry Mountains significantly determines the historical land use. The dominant element of the landscape in 1846 was the forest cover stretched to across the land area and accounted for more than 7541 ha (76.54% of the total account.). Outside the forest are clearly identified permanent grasslands and small arable land. Permanent grasslands were located in the central part of the land and along streams. Meadow vegetation were more than 1238 ha (12.57% land) and pastures around 360 ha (3.65%). Arable land located in a floodplain Čierny Váh area represented 566 ha (5.75%).

T a b l e 3. Correlation coefficients (*r*) for relationship of soil physical, chemical and biological parameters.

parameter	bulk density	porosity	$pHCaCl_2$	C_{ox}	N_{anorg}	P_{avail}	K_{avail}	Mg_{avail}	Pb	Cd	Ni	urease	acid phos-phatase	alkaline phos-phatase
bulk density		**-0.999**$^{++}$	-0.126	**-0.541**$^{++}$	-0.125	-0.144	-0.141	-0.063	-0.108	-0.047	-0.014	-0.088	-0.036	-0.032
porosity	**-0.999**$^{++}$		0.127	**0.538**$^{++}$	-0.129	0.142	0.138	0.057	0.107	0.042	0.014	0.089	0.036	0.033
$pH/CaCl_2$	-0.126	0.126		0.163	-0.146	**0.537**$^{++}$	0.288	0.424^{+}	-0.048	**0.329**$^{+}$	**0.357**$^{+}$	0.255	-0.207	-0.164
C_{ox}	**-0.541**$^{++}$	**0.538**$^{++}$	0.163		0.049	**0.605**$^{++}$	**0.383**$^{+}$	0.261	0.004	0.222	0.221	0.176	0.086	0.022
N_{anorg}	0.125	-0.129	-0.146	0.049		-0.131	0.116	-0.118	0.126	0.034	0.091	0.012	0.119	0.066
P_{avail}	-0.144	0.142	**0.537**$^{++}$	**0.605**$^{++}$	-0.131		**0.562**$^{++}$	**0.368**$^{+}$	0.032	**0.488**$^{+}$	**0.407**$^{+}$	0.297	-0.173	-0.125
K_{avail}	-0.141	0.138	0.288	**0.383**$^{+}$	0.116	**0.562**$^{++}$		0.084	**-0.378**$^{+}$	0.127	**-0.383**$^{+}$	**0.378**$^{+}$	**-0.322**$^{+}$	-0.099
Mg_{avail}	-0.063	0.057	**0.424**$^{+}$	0.261	-0.118	**0.368**$^{+}$	0.084		**-0.425**$^{+}$	0.093	**0.359**$^{+}$	-0.285	-0.281	-0.280
Pb	-0.108	0.107	-0.048	0.004	0.126	0.032	**-0.378**$^{+}$	-0.425^{+}		0.278	**0.546**$^{++}$	-0.057	**0.441**$^{+}$	**0.378**$^{+}$
Cd	-0.047	0.042	0.329^{+}	0.222	0.034	**0.488**$^{+}$	0.127	0.093	0.278		**0.748**$^{++}$	-0.039	0.220	0.258
Ni	-0.014	0.015	0.357^{+}	0.221		**0.407**$^{+}$	**-0.383**$^{+}$	**0.359**$^{+}$	**0.546**$^{++}$	**0.748**$^{++}$		-0.293	**0.492**$^{+}$	**0.354**$^{+}$
urease	-0.088	0.089	0.255	0.176	0.012	0.297	**0.378**$^{+}$	-0.285	-0.057	-0.039	-0.293		0.076	0.233
acid phosphatase	-0.036	0.036	-0.207	0.086	0.120	-0.173	**-0.322**$^{+}$	-0.281	**0.441**$^{+}$	0.220	**0.492**$^{+}$	0.076		**0.912**$^{++}$
alkaline phosphatase	-0.032	0.033	-0.164	0.022	0.066	-0.125	-0.099	**-0.350**$^{+}$	**0.378**$^{+}$	0.258	**0.354**$^{+}$	0.233	**0.912**$^{++}$	

++$P < 0.01$ +$P < 0.05$

Notes: $r < 0.3$ – slight dependence; < 0.5 – moderate dependence; $r < 0.7$ – significant dependence; $r < 0.9$ – statistical dependence; r – statistically significant dependence

Landscape structure in 1949

The dominant group of land use in 1949 were still elements of the forest and semi-natural areas. Overall, occupying more than 7500 ha, this was 76.14% of the cadaster. Second largest group of landscape elements were elements of agricultural land. Overall occupying an area of 2265 ha, this was 23% of the municipal area. The main elements in this region are different types and forms of permanent grassland. The largest element this group have been extensively used meadows along streams, but especially in the central part in the following locations: Doštianky, Grapy, Palenička, Okrúhle, Smrečina, Zálom, Hola and Vysoké a Kobyliarky, covered area 1088 ha (11.05%). Arable land area was 522 ha (5.3%).

Landscape structure in 2010

Changes in the management of the agricultural land in Liptovská Teplička occurred mainly in 1975 after collectivisation. The majority of the arable land was abandoned, part of the cultivated agricultural cooperative and the smaller part an individual as small fields. After succession arable land is now used these lands as extensive meadows and pastures with preserved between. Overview of land use change in the PPF in 1949 and now is presented in Table 4. Forests now occupy 83.56% of the around land. The present species compositions of forests are mainly pine monocultures, which have been planted in place of the original mixed fir–beech forest.

Conclusion

Soil physical properties change not only under the influence of weather conditions, crop year and vegetation pass, but also under the influence of applied management system. During the year and growing season bulk density value also varies depending on water availability in the soil, weather and farming methods. Research showed that soil physical properties get adjusted after a long-term application of ecological farming system and the measured values were stabilised, reaching the levels comparable with the average values for the soil type. Agrochemical soil characteristics did not change significantly during the research period. High doses of organic fertilizers had positive effect on soil fertility and thus indirectly on maintaining soil pH, available nutrients content and retention of humus in soil. Despite this, it is necessary to continuously pay attention to soil reaction as soil is naturally acidified through acid atmospheric fallout as well as calcium uptake by plants. Values of selected heavy metals in the monitored period did not exceed the limit values published in Act No. 220/2004 Coll.

The values of activity of phosphatases and ureases changed minimally during the research period and they refer to the values typical for soils with sparse vegetation. At the same time, it was proven that increasing the content of soil organic matter promotes natural protection of soil enzymes. The analysis of variance confirmed statistically significant effect of experimental year on all observed soil parameters. Effect of experimen-

T a b l e 4. Representation of elements of agricultural landscape structure form in years 1949 and 2010 (Špulerová et al., 2011).

The elements secondary of landscape structure (code legend)	**The historic landscape structure (1949)**		**The present landscape structure (2010)**	
	area (ha)	**area (%)**	**area (ha)**	**area (%)**
Agricultural area				
Large arable land with the presence of non-forest woody vegetation (NDV) to 10 % (2111)			54.00	0.55
Small arable land (2112)	522.75	5.31	4.96	0.05
Intensively used meadows (23111)			196.75	2.00
Extensively used meadows (23112)	1088.85	11.05	276.75	2.81
Abandoned meadows (degree overgrowing NDV to 40 %) (23113)	2.10	0.02	36.48	0.37
Intensively used pastures (23121)			225.55	2.29
Extensively used pastures (23122)	649.31	6.59	412.41	4.19
Abandoned pastures (degree overgrowing NDV to 40 %) (23123)	2.85	0.03	56.89	0.58
Mosaic of arable land and permanent grasslands (2415)			49.17	0.50

tal locality, with the exception of pH/$CaCl_2$, C_{ox} and N_{anorg}, on other soil parameters was also statistically significant. Landscape structure changes were identified from historical military maps and historical and present aerial orthophotographs using GIS equipment. Specific landscape structure of the study area represents the relatively stable territory with these following significant changes. The dominant landscape element in all periods was the forest cover. In 1846 outside the forest are identified permanent grasslands and small arable land. In 1949 second largest group of landscape elements were elements of agricultural land (more than 23% of study area). The main elements are permanent grasslands and arable land. After collectivisation in 1975 the majority of the arable land in Liptovská Teplička was abandoned (Baránková et al., 2011; Špulerová et al., 2013). After succession, overgrowing arable land is now used as extensive meadows and pastures.

Acknowledgements

The study was supported by VEGA 1/0627/12 Diversity, resiliency and health of ecosystem in different farming systems and polluted territories in anthropogenic land, KEGA 012PU-4/2012 Preparation and realization of research focused on creating teaching aids for education of environmental subjects, KEGA 023UKF-4/2011 Terrain geoecological research as a base for creating of education equipment and VEGA 2/0117/13 Assessment of status and dynamics of habitats using combination of modelling and remote sensing.

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Ekológia (Bratislava) Vol. 32, No. 2, p. 211–219, 2013
doi:10.2478/eko-2013-0018

TRANSFER OF RISK ELEMENTS IN SOIL–BILBERRY SYSTEM

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Abstract

Kuklová M., Kukla J.: Transfer of risk elements in soil–bilberry system. Ekológia (Bratislava), Vol. 32, No. 2, p. 211–219, 2013.

Transfer of Al, Cr and Ni in the soil–plant (*Vaccinium myrtillus* L.) system was examined in four forest ecosystems in the localities Muráň (skeli-humic podzols) and Hliníky (dystric cambisols) in the protected zone of the NP Slovenský raj. In case of Al, the transfer coefficients were low, exceeding 1 only in the litter horizon on the damaged plot in the locality Muráň. The Al content in soils was the highest at a depth of 60–70 cm (10 249 mg kg^{-1}) on the undamaged plot in Hliníky. The amounts of Al accumulated in bilberries were higher than the background value in plants, and they made 11–22% of the maximum Al contents detected in Ooh horizons of the studied soils. Cr on the damaged plot in the locality Muráň displayed higher transfer coefficients (range 1.09–11.3) in comparison with the other plots (0.03–0.59). Considering the value representing the maximum Cr amount detected in Ooh horizon in the corresponding locality as 100%, the content of Cr in bilberries growing on the damaged plot in Muráň was 109%, in contrast to 2% on the damaged plot in Hliníky. The concentrations of Ni in soils exceeded limit values in the surface humus horizons on all studied plots. Ni displayed higher transfer coefficients, exceeding 1 only on the damaged plot in the locality Muráň. Bilberries had accumulated 6–28% Ni in the locality Muráň, and 2–6% in the locality Hliníky of the maximum amounts detected in Ooh horizons of soils. The differences in mean values of transfer coefficients for Al, Ni and Cr were statistically significant ($p < 0.05$).

Key words: forest ecosystems, acid soils, *Vaccinium myrtillus* L., risk elements, transfer.

Introduction

From Slovak regions, Central Spiš is exposed to the most severe impact of toxic and risk elements. Effects of a wide range of pollutants result in reduction of forest and agricultural production and in contamination of food chain with alien substances (Rajčáková et al., 2003; Jamnická et al., 2007; Takáč et al., 2008). Toxic and risk elements belong to the primary environmental contaminants. They are present in all components of the living environment (Píš, Nováková, 2002; Pichler et al., 2006; Janík, 2010). Unlike organic substances, they avoid chemical degradation and accumulate in soil surface layers. Their main sources are waste, fossil fuels and metallurgy. These materials may also be released from natural sources (Komanická, 2009). Their uptake into plants works through stomata or together with uptake of soil nutrients. The amount of toxic and risk elements penetrated in plants from soil is dependent on the degree of soil contamination (concentrations and forms of heavy metals), character of soil-ecological conditions, especially soil reaction values, humus content, redox state in neighbourhood of root systems in the presence of microbial decomposition of organic matter, water dynamics, temperature etc. (Makovníková et al., 2006; Kuklová, Kukla, 2006).

In this work, the extent of soil contamination induced by human activities in damaged and undamaged forest stands is evaluated. Concerned are selected risk elements and their transfer in aboveground phytomass in bilberry (*Vaccinium myrtillus* L.).

Material and methods

The research ran in four forest ecosystems on two undamaged (B, D) and two damaged (A, C) plots situated in localities Muráň (1080–1110 m asl, skeli-humic podzols) and Hliníky (950–960 m asl, dystric cambisols) in the protected zone of the National Park Slovenský raj (Kukla, Kuklová, 2008). Hemi-oligotrophic geobiocoenoses in the locality Hliníky belong to the 5-th fir-beech forest vegetation tier (fvt), geobioceone type group (gtg) *Abieti-Fageta inferiora*. The active reaction values pH_{H_2O} in this site in the surface humus layer range between 3.65 and 4.11, in mineral soil layers between pH_{H_2O} 3.55 and 4.50. The geobiocoenoses in the locality Muráň belong to the 6-th spruce-beech-fir fvt, gtg *Fageta abietino-piceosa*. The active soil reaction values pH_{H_2O} in the surface humus layer in this locality range from 3.61 to 4.52, in mineral soil layers between 3.22 and 3.75. The values of C/N ratio in separate horizons of the studied soils are in the cover humus from 33.9 to 50.7, in the surface soil horizons (2–6 cm) from 17.02 to 38.79 and in the lower situated horizons from 9.2 to 15.8. Šály (1978) reports for forest soil humus C/N values ranging between 8 and 20, with higher values indicating poorer humus quality.

There were sampled soil surface humus layers and mineral layers. The samples were air-dried and sieved with a mesh of 2×2 mm. Risk elements (Al, Cr, Ni) were evaluated according to guidelines set by the MA SR (1994) in 2M extract of HNO_3 (ratio of fine earth to 2M HNO_3 1:10, stirring for 2 hours and filtering) using an appliance Varian Spectr. AA 300/400.

Plant material was sampled randomly from 400 m^2 phytocoenological relevé plots. Green twigs growing out from creeping stems of *Vaccinium myrtillus* L. were collected. The contents of Cr and Ni in bilberry shoots were determined by microwave decomposition of plant material in AAS ETA, the content of Al with ICP AES. The input of the studied elements (Al, Cr, Ni) from soil to plant (the plant/soil transfer coefficient, TC) was calculated as the ratio between mean concentration value in plant dry mass and in soil.

Results and discussion

Amounts of risk elements in studied soils are presented in Tables 1–4. **Aluminium** is the third most abundant element in the Earth's crust, occurring at about 8% (Delhaize, Ryan, 1995). Al is either a main or secondary component of many minerals, especially of all silicates (Kabata-Pendias, 2011). This element is released from acid fallout and therefore may damage forests (Maňkovská, Oszlányi, 2010). Most aluminium is present in the crust surface, in plants it occurs in lower concentrations. Increased concentration of Al in soils with acidic or very acidic

T a b l e 1. Content of risk elements in skeli-humic podzol in locality Muráň (damaged stand A).

Horizon	**Layer (cm)**	**Al**	**Ni**	**Cr**
		(mg kg^{-1})		
Ool	1–2	225.0	5.27	0.48
Oof	1–2	421.0	8.94	0.52
Ooh	7–8	2 482.0	18.24	1.04
Aop	2–6	862.7	1.37	0.31
E/C1	20–40	629.9	0.64	0.10

T a b l e 2. Content of risk elements in skeli-humic podzol in locality Muráň (undamaged stand B).

Horizon	Layer (cm)	Al	Ni	Cr
		(mg kg^{-1})		
Ool	1–2	473.0	10.11	0.66
Oof	1–2	1 024.0	8.80	0.88
Ooh	7–8	1 662.0	10.74	0.97
Aop	2–6	471.8	0.81	0.20
E/C1	20–40	386.6	0.53	0.02

T a b l e 3. Content of risk elements in dystric cambisol in locality Hliníky (damaged stand C).

Horizon	Layer (cm)	Al	Ni	Cr
		(mg kg^{-1} d.m.)		
Ool + Oof	2–3	374.0	10.23	0.38
Ooh	2	1 789.0	8.97	2.18
Aop	2–6	3 467.6	3.75	3.16
Bvs_1	10–20	4 825.7	2.75	3.68
Bvs_2	25–35	6 062.8	3.31	4.02
Bvs_3	40–50	6 806.8	2.27	3.38
Bvs_4	60–80	9 363.2	2.62	3.97

T a b l e 4. Content of risk elements in dystric cambisol in locality Hliníky (undamaged stand D).

Horizon	Layer (cm)	Al	Ni	Cr
		(mg kg^{-1})		
Ool + Oof	3	597.0	22.41	0.91
Ooh	2	1 588.0	9.97	1.81
Aop	2–6	3 469.2	2.19	2.02
Bvs_1	10–20	4 763.5	2.17	3.12
Bvs_2	30–50	7 109.2	2.20	4.53
Bvs_3	60–70	10 249.2	2.03	5.81
Bvs_4	60–80	9 363.2	2.62	3.97

reaction represents a serious harmful factor for plant growth (Mossor-Pietraszewska, 2001). The toxic impact of active aluminium on plants may be either direct or indirect. Aluminium causes changes to morphology of plant root system, changes in root hardness and reduction of amount of hair roots. Accumulated aluminium does not allow intake of other metals, primarily phosphorus – causing their deficit by fixing them. Contents of this element in plants vary greatly, depending on soil and plant factors. Some species of Al-accumulating plants may contain more than 1 000 mg Al kg^{-1} (Kabata-Pendias, 2011).

Aluminium content in surface humus in the studied soils was 225–2 482 mg kg^{-1} of dry matter, being somewhat higher in podzols with amounts increasing downwards – from the litter layer to horizon of humification. Maximum Al values were observed in the 7–8-cm-thick Ooh horizon of podzol on the damaged plot at the locality Muráň (Table 1). Substantially lower amounts were found in the mineral layers of podzols (387–863 mg kg^{-1}) than in less acid cambisols (3 468–10 249 mg kg^{-1}). This fact seemed connected with a very high proportion of sandy fraction in podzols (62–71%) compared to cambisols (20–42%). The Al content was the highest at a depth of 60–70 cm on the undamaged plot D (10 249 mg kg^{-1}) in locality Hliníky (Table 4) and it was substantially lower, as states for soil Al values McLean, Bledsoe (1992).

In plants Al is present in lower amounts. Plant species and even cultivars of the same species differ considerably in their ability to take up and transport aluminium, depending on plant tolerance to the Al excesses. For example, Chinese tea contains Al at levels from 676 to 1875 mg kg^{-1} (Kabata-Pendias, 2011). According to Maňkovská (1996), limit concentrations of Al in plants range between 90 and 530 mg kg^{-1} of dry matter. Uptake by plants is only possible from acid environment. Average aluminium contents in bilberries growing on studied plots ranged as follows [mg kg^{-1}]: 194 (C-plot) < 287 (A-plot) < 300 (D-plot) < 352 (B-plot) and they were 2.4 to 4.4 times higher than the background values in plant reported by Markert (1995).

Transfer coefficients can serve as indicators for element uptake by plants. In case of aluminium lower transfer coefficients were obtained, exceeding 1 only in the litter horizon on the damaged plot A, Fig. 1. The amounts of Al accumulated by bilberries made 12–22% and 11–19% in Muráň and Hliníky, respectively, of the maximum Al amounts detected in Ooh soil horizons. The values of Al transfer coefficients indicate that the element is relatively poor absorbed by *V. myrtillus* species.

Chromium and nickel are primary important trace elements. Present in excessive amounts in air, water and soil, they can lower the soil quality. Their toxicity depends on solubility, absorbance, way of transport and chemical reactivity. Present in plants, the two elements induce conspicuous toxic symptoms (inhibition of growth, altered conformation of bio-molecules, al-

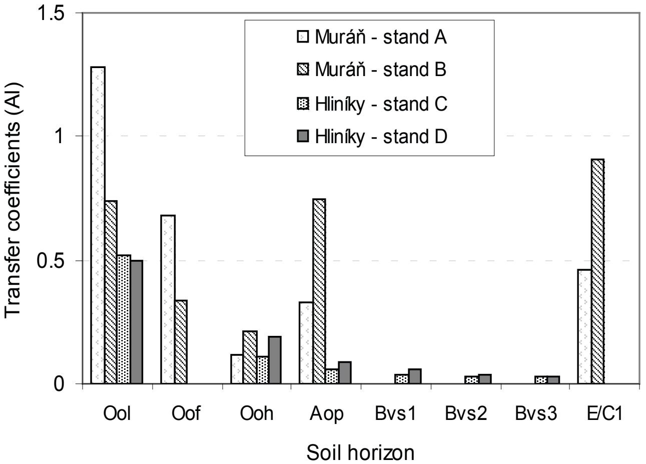

Fig. 1. Transfer coefficients for Al in the soil–bilberry system.

tered cell ultrastructure, DNA damage, disturbed metabolisms and impaired overall vitality). Chromium toxicity is dependent on oxidation grade. Especially toxic is Cr^{6+}, the transfer of which in the food chain may be considerable.

The abundance of Cr in the Earth's upper crust is about 100 mg Cr kg^{-1}. The world soil average content of Cr in soils has been established as 60 mg Cr kg^{-1}. Soil Cr is released from parent rocks, higher contents are generally found in soils derived from argillaceous sediments (Kabata-Pendias, 2011). The Report on State of the Environment in SR (ME SR, 2008) presents 24.5 mg Cr kg^{-1} at 10-cm depth for arable soils (group cambisols) in Slovakia. By Decision MA SR (1994), soils are considered contaminated if exceeding 130 mg Cr kg^{-1} of dry matter. The reference value set for chromium in 2M HNO_3 leachate is 10 mg Cr kg^{-1}. By Act No.220/2004, limit values for chromium in agricultural soil represent 50–90 mg kg^{-1}, dependent on the soil type (determined with aqua regia).

Chromium content in surface humus of the studied soils ranged 0.38–2.18 mg kg^{-1} of dry matter. Its contents in both soil subtypes increased downwards from the litter layer to the horizon of humification (Tables 1–4). In Ooh horizons of cambisols, it was higher by 50% than in Ooh horizons in podzols. Considerably higher chromium amounts were observed in mineral layers of cambisols (3.12–5.81 mg kg^{-1}) than in acid podzols (0.02–0.10 mg kg^{-1}). The soil sampled from our study plots did not display limit-exceeding chromium values. Al-Khashman, Shawabkeh (2006) observed relatively high concentrations of metals in the soil samples in an area close to a cement factory (south Jordan), while the concentration of chromium was low (6–22 mg kg^{-1}). The authors observed that Cr was mostly accumulated on the soil surface (0–10 cm); the amount found in the soil layer of 10–20 cm was much lower. This fact is not in accordance with our observations in Hliníky where the Cr contents in Dystric cambisol increased downwards to the mineral soil layers.

The most available to plants is Cr^{6+}, which is the very unstable form under normal soil condition and its availability depends on soils properties, especially on soil texture and pH. Also, Cr^{3+} and several complex Cr anions may be easily available to plants. Mean contents of Cr in cereal grains fluctuated from 0.01 mg kg^{-1} to 0.09 mg Cr kg^{-1}. Relatively high contents of Cr are accumulated in carrot (0.13 mg kg^{-1}), onion (0.16 mg kg^{-1}) and cabbage (0.13 mg kg^{-1}) (Kabata-Pendias, 2011). Cr is not essential element for plants, but plant concentrations above 5 mg kg^{-1} are according to Maciejewska-Rutkowska et al. (2007) considered toxic to plants. Maňkovská (1996) sets limit concentrations for chromium in plants 0.03–10 mg kg^{-1}. Average Cr content in bilberries growing on studied plots ranged as follows [mg kg^{-1}]: 0.05 (B-plot, C-plot) < 0.29 (D-plot) < 1.13 (A-plot). The least amounts of chromium were observed in aboveground phytomass of bilberries growing on plots B and C, the highest on damaged plot A (Muráň).

Cr on the damaged plot A (Fig. 2) displayed higher transfer coefficients (1.09–11.3), which means that it was more abundant in the aboveground bilberry biomass than in the soil. The transfer coefficients on the other plots were comparatively low. The content of Cr accumulated in bilberries made 109% on the damaged plot A (Muráň), in contrast to 6% on the undamaged plot B of the maximum Cr amounts found in Ooh horizons of podzols. The Cr amounts accumulated in bilberries growing at the locality Hliníky ranged from 2 to 16% of the maximum Cr content detected in Ooh horizons of cambisols. The values of Cr transfer coefficients in the locality Hliníky were distinctly lower than the value of 1, which indicated that Cr was relatively poorly absorbed by *V. myrtillus* species. Better ability to accumulate Cr was showed by this

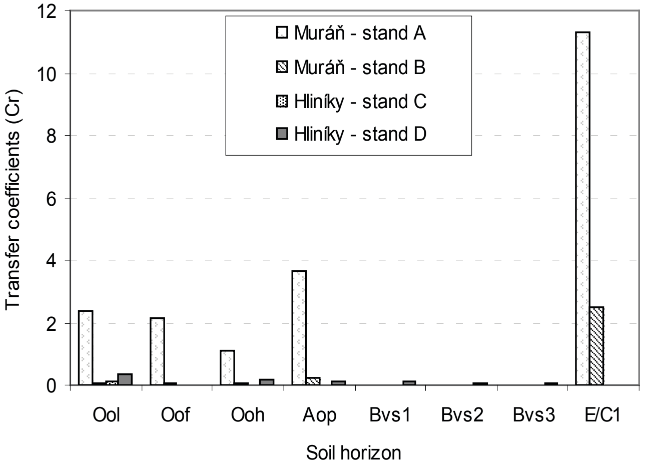

Fig. 2. Transfer coefficients for Cr in the soil–bilberry system.

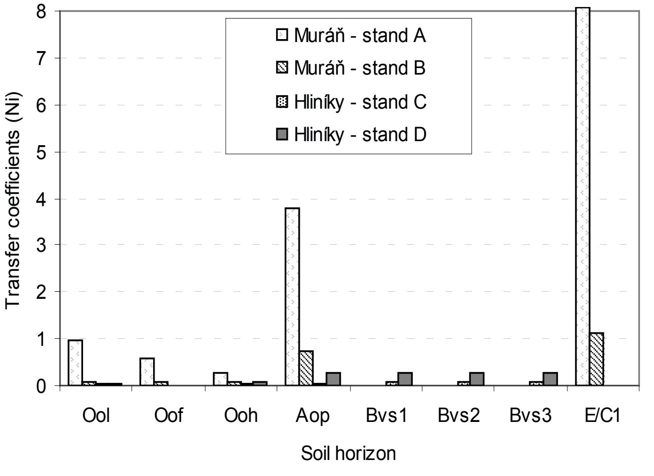

Fig. 3. Transfer coefficients for Ni in the soil–bilberry system.

plant species on the damaged plot in Muráň where the value of transfer coefficients exceeded far beyond the value of 1.

In the Earth's crust, the mean **nickel** abundance has been estimated around 20 mg kg^{-1}. The concentration of Ni in surface soils reflects the additional impact of both soil-forming processes and anthropogenic activities. Ni is quite abundant in all soil groups, with more abundant accumulation observed in cambisols and calcisols (Kabata-Pendias, 2011). The most accessible Ni forms occur in soils with pH 6.5–7.0. The Report on the State of the Environment SR (ME

SR, 2008) declares for arable soils in Slovakia (group of cambisols) at depth of 10 cm on average 9.2 mg of the total Ni kg^{-1}. The Decision by MA SR (1994) declares soil contamination at levels exceeding 35 mg Ni kg^{-1}. The reference value in determining Ni in 2M HNO_3 leachate represents 10 mg Ni kg^{-1} of dry matter. According to the Act No. 220/2004, limit values for Ni in agricultural soil in dependence on the soil type (decomposition in aqua regia) are 40–60 mg kg^{-1}. The limit (critical) value set for Ni in relation to soil and plants (leachate 1 mol L^{-1} ammonium nitrate) is 1.5 mg Ni kg^{-1}.

Ni content in surface humus of the studied soils ranged between 5 and 22 mg kg^{-1} of dry matter. (Table 1–4), being substantially higher than in the mineral layer (0.5–3.8 mg kg^{-1}). A steeper increase in Ni content (by 70%) from horizon Ool to Ooh was observed on the damaged plot A (Muráň). On undamaged plot B, Ni distribution patterns in surface humus layers were fairly uniform; on the other hand, in case of cambisols Ni content in the horizons Ool and Oof was higher than in Ooh horizon. The soil samples were compared with the reference value set for determining Ni in 2M HNO_3 leachate (MA SR, 1994). Beyond-limit Ni amounts were recorded in the surface humus horizons of the study plots. High concentrations of Ni in the organic material (5–190 mg kg^{-1}) were also observed by Uhlig, Junttila (2001) in the north-eastern part of Sør-Varanger, Norway. In general, the major proportion of heavy metals from anthropogenic sources occurs in the upper organic layer (Hazlett et al. 1984; Uhlig, Junttila, 2001) in form of salts or bound in metal–organo complexes.

Ni present in high amounts limits plant growth and suppresses its photosynthesis and transpiration. Ni limit content in plants ranges between 0.1 and 5.0 mg kg^{-1} of dry matter (Maňkovská, 1996). Markert (1995) states the upper limit of the natural range as 1.5 mg kg^{-1}. In food plants, Ni content varies from 0.06 to 2 mg kg^{-1}, with the lowest value in apples and the highest in cucumber. Average Ni contents in cereal grains from different countries vary from 0.34 to 1.28 mg kg^{-1} (Kabata-Pendias, 2011). Average Ni contents in bilberries growing on studied plots ranged as follows (mg kg^{-1}): 0.20 (C-plot) < 0.57 (D-plot) < 0.60 (B-plot) < 5.16 (A-plot).

Ni displayed higher transfer coefficients (3.7–8.1), exceeding 1 only on the damaged plot A (depth 2–40 cm) in the locality Muráň (Fig. 3). The mean values obtained on the other plots were relatively low (<0.41). Bilberry had accumulated 28% Ni on the damaged plot A (Muráň), and 6% on the parallel undamaged plot B of the maximum Ni amounts found in Ooh horizons of podzols. The Ni amounts accumulated in bilberries growing at the locality Hliníky made 2–6% of the maximum Ni content detected in Ooh horizons of cambisols. Plant/soil transfer coefficients in the locality Hliníky indicate that Ni is relatively poorly absorbed by *V. myrtillus* species. Better ability to accumulate Ni by this plant species was observed on the damaged plot in Muráň with the transfer coefficients values beyond the value of 1.

Zeidler (2005) investigated the contents of Ni in soils and plants in the alluvial plain of the Morava river. The mean values of TC for Ni in *Urtica dioica* species varied from 1.2 (root) to 2.9 (leaves), in *Taraxacum* sp. from 1.2 (leaves) to 0.6 (root), and these results were similar to ours obtained by investigation of *Vaccinium myrtillus* species growing in damaged stand at locality Muráň, where Ni displayed higher transfer coefficients, exceeding value 1.

The values of mean transfer coefficients are presented in Table 5. The differences in mean values of transfer coefficients for Al, Ni and Cr were statistically significant ($p < 0.05$). Aluminium was better accumulated by bilberry growing in locality Muráň (both stands A, B) than in the locality Hliníky ($F_{(3, 18)} = 4.2562$, $p = 0.0194$); nickel and chromium were better accumulated by bilberry in locality Muráň (stand A) than in the other stands ($F_{(3, 18)} = 3.3947$, $p = 0.0405$ nickel; and $F_{(3, 18)} = 4.8847$, $p = 0.01174$ chromium).

T a b l e 5. Differences in mean transfer coefficients in the soil–bilberry system between forest stands (ANOVA, LSD test).

Locality	**Muráň**		**Hliníky**		**Sample size**	**Significance level (α)**
Soil	**Podzol**		**Cambisol**			
Forest stand/ risk elements	**A**	**B**	**C**	**D**		
Al min–max	0.57 ± 0.44 0.12–1.28	0.59 ± 0.30 0.21–0.91	0.13 ± 0.19 0.03–0.52	0.15 ± 0.18 0.03–0.50	22	p < 0.05 (A–C,D) (B–C,D)
Ni min–max	2.73 ± 3.29 0.28–8.06	0.41 ± 0.49 0.06–1.13	0.05 ± 0.03 0.02–0.09	0.19 ± 0.11 0.03–0.28	22	p < 0.05 (A–B,C,D)
Cr min–max	4.11 ± 4.11 1.09–11.30	0.59 ± 1.07 0.05–2.50	0.03 ± 0.04 0.01–0.13	0.14 ± 0.09 0.05–0.32	22	p < 0.05 (A–B,C,D)

Conclusion

Transfer of risk elements between soil and plants is an important component of the elements cycle in the nature. It is a process driven by a number of natural and anthropogenic factors. The final values of transfer coefficients for Cr and Ni resulted in finding that the highest average transfer coefficients (TC 4.1 and 2.7, respectively) were on the damaged plot A – Muráň. The research results allowed concluding about a strong influence of physical and chemical properties of very acidic skeli-humic podzols in the locality Muráň on input of Cr and Ni into the aboveground biomass in bilberry. On the other hand, mean transfer coefficients for Al were low on all the analysed plots (TC 0.13–0.59). In the soil samples, beyond-limit values were observed only in case of Ni in the surface humus horizons. Our research results have confirmed that the studied species accumulated risk elements, and that these elements could circulate in the soil–plant system.

Acknowledgements

We appreciate the support from the Science Grant Agency of the Ministry of Education of SR and the Slovak Academy of Sciences (project No. 2/0027/13) and by the project implementation: Extension of the centre of Excellence „Adaptive Forest Ecosystems“, ITMS: 26220120049, supported by the Research & Development Operational Programme funded by the ERDF.

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Ekológia (Bratislava) Vol. 32, No. 2, p. 220–241, 2013
doi:10.2478/eko-2013-0019

SAFETY ASSESSMENT FOR SPATIAL DEVELOPMENT

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Abstract

Rehák D., Sikorová K., Senovský P.: Safety assessment for spatial development. Ekológia (Bratislava), Vol. 32, No. 2, p. 220–241, 2013.

The article deals with the problems of operable safety assessment for spatial development to promote the preventive protection of population, engineering infrastructure and the environment against negative effects of spatial development. At present, many methods available for semi-quantitative risk analysis exist, but there is no method completely suitable for assessment of risks associated with spatial development. This is why a new method – Spatial Development Impact Assessment, which is based philosophically on the Fire & Explosion Index, Hazard & Vulnerability Index and Hazard & Impact Index – is presented in the article. The article describes the main tools of this method, namely assessment process algorithm, catalogue of hazard and asset groups and spatial development impact matrix. It demonstrates, by a case study on the safety assessment for spatial development using an online software tool developed for this purpose, the application of the method.

Key words: environmental protection, population, technical infrastructure, analytic method, risk.

Introduction

Spatial development is a significant part of development for human population. Through the spatial development, people tried to adapt to newly populated areas according to their needs and increase utility value in their benefit. This was particularly the construction of settlements and other components of equipment in this area. With agglomeration sprawl occurs also an approximation of the dense settlement into the direct proximity of heavily industrially used areas, which carries with it additional risks with the potential to affect not only the environment but also the health of the population directly.

The basic strategic document in the area of safety for spatial development in the Czech Republic is the State Environmental Policy of the Czech Republic (Ministry of Environment, 2004a), which defines a consensual framework for long-term and mid-term development of environmental aspect of sustainable development (Belčáková, 2012). The second strategic document is the Strategy of Sustainable Development of the Czech Republic (Ministry of Environment, 2004b). This strategy creates a framework for elaborating the materials of conceptual character (departmental policies and action programmes). It is a starting point for strategic decision making within individual departments, inter-departmental co-operation and the co-operation among interest groups.

The spatial development in the Czech Republic follows the Act on Spatial Planning and Building Code (Act, 2006). The spatial development is carried out in compliance with this Act and on the basis of spatial planning. The task of spatial planning is, besides other things, to assess the effects of the policy of spatial development, the principles of spatial development and a spatial plan on a balanced relation between spatial conditions and the environment, economic development and a unity of the population living on the territory (hereinafter 'assessment of impacts on the sustainable development of the territory').

When assessing the consequences of concepts and intentions, the procedure is followed according to the Act on Environmental Impact Assessment (Act, 2001), which, in compliance with the law of the European Union (Council Directive, 1985, 1997; Directive, 2001), amends the assessment of impacts on the environment and public health as well as on the procedures followed by physical entities, legal entities, administrative authorities and territorial self-administration units (municipalities and districts) in the course of assessment. This Act is followed when assessing the impacts on public health and the environment. However, assessment of the impacts of spatial development on population and technical infrastructure cannot be performed according to the Act in order to ensure a social and technical safety for spatial development.

To this purpose it is appropriate to find solutions in a proactive approach to environmental protection by using preventive tools. However, at present there is no methodology that would be able to evaluate the safety of spatial development (Navratilova et al. 2013). On this basis, are presented below, at least such methodologies, which deal with similar problems, which can serve as a basis for further development process.

The article follows and further elaborates, with an emphasis on practical application, a contribution presented at the end of 2010 in a national journal (Řehák, Dvorak, 2010) and a case study presented in 2011 in Poland (Řehák et al., 2011b). In these journals only the basic framework of this problem was presented.

Material and methods

This part of article presents the most significant materials, methods and approaches that have become the bases for the formation of algorithm for the process of safety assessment for spatial development.

Semi-quantitative methods of risk analysis

At present there are many methods of risk analysis employed in the area of safety engineering (Bartlova, Balog, 2007; Senovsky et al., 2009; Danihelka et al., 2006), but none of them is fully suitable for the analysis and assessment of safety of spatial development. Detailed analysis of the subject matter identified three relevant semi-quantitative methods of risk analysis on which the development of a new tool of safety assessment for spatial development is based. These methods are Fire & Explosion Index, Hazard & Vulnerability Index and Hazard & Impact Index.

The Fire & Explosion Index Method (AIChE, 2010) is a step-by-step index system the aim of which is to realistically assess the threat of fire and explosion depending on the potential of technological facility. The quantitative parameters used in the system are based on the historical data acquired from the detailed analysis of accidents in the past as well as on the preventive measures commonly used in technological practice. The aim of the Fire & Explosion Index may be seen mainly in the quantification of possible damage caused by fire or explosion, the identification of equipment which may escalate the accident and inform the management on the outcomes of the analysis.

By a thorough analysis of methods and systems of impact assessment, it seems that the step-by-step analysis of the Fire & Explosion Index Method is an optimal decision-making algorithm. Its advantages are mainly simplicity, clarity and unambiguity when implementing individual stages of the method. However, the process of the method itself is totally unsuitable as it is specifically aimed only at areas of hazard, i.e. fire and explosion. At the same time, it may be stated that the method is rather time demanding.

Another necessary condition of objective evaluation is a complex assessment of all risks in the territory. This approach began to promote from the beginning of the 21st century. In this context, we can mention the Swiss KATARISK (2003) or even HVA method, sometimes also known as HVE method: H – hazard, V – vulnerability, E – value of the elements at risk (SIPROCI, 2007). For assessment of the territory, this method was promoted by the project SIPROCI (International Response to Natural and Man-made catastrophes SIPROCI), which from 2004 to 2007 has had the task of participating countries to predict, prevent and respond to natural or man-made disasters. One of the outputs of the project was to create a uniform methodology for mapping risks.

The Hazard & Vulnerability Index Method (Vojkovska, Danihelka, 2002) is applied for assessing the impact the accidents have on the environment. It may also be used for assessing and prioritizing the risks on the territories up to the size of the region. The assessment of larger territorial units would require the implementation of geographic information system (GIS). The method is based on clear mathematical procedures which provide clear overview of final index values and subsequent determination of impacts the hazardous substances have on the environment (Sikorova, 2009). At the same time, the clarity of indexation is supported by the principle of separate indexation for individual environmental elements. Therefore, the above-mentioned principle was applied not only within the indexation, but also in the classification of negative aspects of spatial development and areas of their impacts.

The method of preventive military training environmental impact assessment called the Hazard & Impact Index (Řehák et al., 2011a) is a semi-quantitative method which was developed by the team of Czech environmentalists from 2007 to 2009 within the project of the Czech Academy of Sciences Grant Agency. After being completed in the first half of 2010, it was the subject of practical testing. After successful negotiations with the Czech Ministry of Defence Logistic Section, the method was implemented in the Army of the Czech Republic in the form of guidelines in June 2010 (Rehak et al. 2010). The algorithm used the outcomes of study aimed at the methods of technological risks analysis based on a semi-quantitative assessment. The final algorithm comprises individual steps determining the level of risk to the environment caused by military training.

Its advantages are mainly simplicity, clarity, unambiguity and operability when applying the individual stages of the method. Therefore, the assessment algorithm was used when developing the assessment process algorithm, which is the key part of the environmental tool for spatial development impact assessment.

Geographic information system tools

GIS is one of the suitable tools which can be used for risk analysis of territorial unit in general, e.g. for the risk source localization, creation of emergency scenarios or combined risk assessment in the territory (Hrdina et al., 2010). GIS software, convenient as a support for graphical and geospatial evaluation of safety for spatial development is, for example, ESRI product ArcGIS for Desktop - Advanced (previously known as ArcInfo). This software contains more than 200 tools for advanced analysis and geoprocessing, data management, mapping and visualization, advanced editing etc. This is the highest license level of ArcGIS for Desktop (ESRI, 2012). Mentioned software was chosen because of its most common use in the bodies of state administration and public authority in the Czech Republic, in comparison with other GIS solutions.

For the evaluation process it is necessary to collect sufficient data materials for researched territory, especially digital topological model of territory, and also other topographic data on other objects of interest such as settlements, economic and cultural buildings, pipelines, but also data on water flows, or general character of the landscape.

For the case study presented in this article, digital topographic model of the Czech Republic territory derived from the image base map of the Czech Republic 1:10 000 ZABAGED created by the Czech Office for Surveying, Mapping and Cadastre was chosen (ZABAGED, 2012). As an additional data source ZABAGED extension containing water information DIBAVOD intended to create thematic cartographic outputs with water management topics and themes of water protection was used. Administrator and provider of data is T. G. Masaryk Water Research Institute (DIBAVOD, 2012) and data are provided free of charge. They are also used in some data belonging to Nature Conservation Agency of the Czech Republic concerning the classification of protected landscape areas.

Results

The essential prerequisite of social, technical and environmental safety for spatial development is to assess preventively all possible risks of planned spatial development and minimize them prior to the realization of spatial development. The safety assessment for spatial development is rather a complicated activity during which it is necessary to consider a large number of various input data and factors, which may significantly affect these data, in particular time and location.

In this part authors present a safety assessment tool for spatial development, which was developed to support a proactive approach to environmental safety. This tool is based on the principle of semi-quantitative assessment of potential negative spatial development aspects and areas of their possible impact. The aim is to assess realistically the potential hazards resulting from spatial development. The tool was developed in compliance with national legal regulations and thus the process of impact assessment will be acceptable from both technological and legislative viewpoints.

Assessment process of algorithm

The following part of the article outlines the structure of the assessment process of algorithm evaluating the impacts of spatial development on population, infrastructure and the environment. This algorithm defines basic relations among individual elements of the process, which are divided into two basic groups: (1) the group of hazards, which includes individual negative aspects of spatial development (ISO, 2004); (2) the group of assets, which includes population, infrastructure and the environment. The algorithm itself consists of individual steps, which result in determining the level of potential risk that the elements of the asset group will be damaged due to spatial development (see Fig. 1).

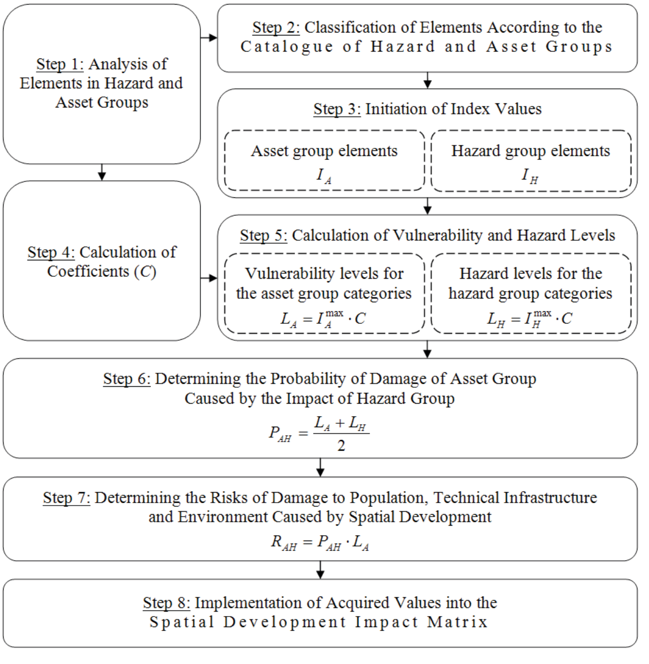

Fig. 1. Assessment process of algorithm.

Step 1: Analysis of elements in hazard and asset groups

The analysis of elements in hazard and asset groups is the essential step in the assessment process of algorithm. The analysis consists in the setting of all social, technical and environmental aspects of planned spatial development with the potential negative impacts on population, technical infrastructure and the environment. This part of the analysis may be carried out according to the data from territorial plans or available indicators. The analysis of the elements of the asset group located in the planned area of spatial development consists in identifying all elements within the subgroups entitled as population, technical infrastructure and the environment, the value of which may be reduced or totally lost due to the negative impact of threats. This analysis may use information from maps and state administration authorities (e.g. district fire rescue corps, regional government and municipal authorities).

Step 2: Classification of elements according to the catalogue of hazard and asset groups

In the next step, it is necessary to classify the elements according to the catalogue of hazard and asset groups, which consists of individual categories and their elements. There are the categories of hazard group (i.e. the individual negative aspects of spatial development) and the categories of the asset group (i.e. categories of the population, technical infrastructure and the environment).

Step 3: Initiation of index values of the elements in hazard and asset groups

Once the elements are classified into categories it is necessary to initiate the index values of the elements of hazard group (I_H) and the elements of the asset group (I_A). Thus, the elements are assigned corresponding index values.

Step 4: Calculation of coefficients

Another step of the algorithm is the calculation of coefficients (C). The user adds selected criteria into preset formulae and then various coefficients are calculated for both hazard group and asset group. The final coefficients consider variables such as range, frequency and probability.

Step 5: Calculation of hazard and vulnerability levels

The calculation of hazard levels for individual categories of hazard group (L_H) and vulnerability levels for individual categories of the asset group (L_A) is made with the help of easy mathematical operations. The level of each category is calculated as the product of maximum index value of initiated elements belonging to the given category and coefficients – see formula (1).

$$L = I^{\max} \cdot C \qquad (1)$$

Step 6: Determining the probability of damage of the asset group caused by the impact of hazard group

Determining the probability of damage (P_{HA}) of the asset group caused by the impact of hazard group starts from the logical reasoning that this probability of damage is the highest if

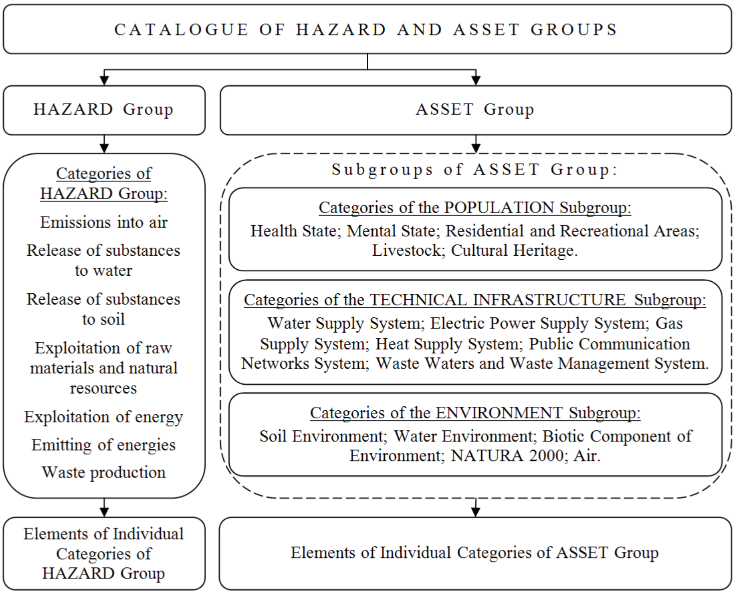

Fig. 2. Catalogue of hazard and asset groups.

the category with the highest level of hazard has an impact on the category with the highest level of vulnerability and vice versa. Mathematically the probability of damage is determined by the arithmetic average of hazard and vulnerability levels of the assessed categories (see section 'Relations defining assessment process of algorithm').

Step 7: Determining the risks of damage to population, technical infrastructure and environment caused by spatial development
Last step in the assessment process is determining the risks of damage to population, technical infrastructure and the environment caused by spatial development (R_{HA}). The calculation of such risk is based on general platforms (ISO, 2009; Rehak, 2012). The level of risk is then determined as the product of vulnerability level of a category of the asset group and the probability related to the assessed categories of hazard and asset groups (see section 'Relations defining assessment process of algorithm').

Step 8: Implementation of acquired values into the spatial development impact matrix
The outcome of the assessment process will be the matrix presenting the potential level of risk for population, technical infrastructure and the environment caused by intended spatial development (see section 'Spatial development impact matrix').

Catalogue of hazard and asset groups and coefficients

The catalogue of hazard and asset groups is a significant part of method for safety assessment of the spatial development. It consists of individual categories and elements. These categories

T a b l e 1. Asset group elements.

Categories	**Elements** (I_A)
Soil environment	Arable soil
	Hop-field and vineyard
	Garden
	Orchard
	Meadows and pastures
	Non-agricultural land of agricultural land resources
	Lands with stands of green vegetation
	Developed areas and roads
Water environment	Sources of drinking water and their first level protection zones
	Water sources' second level protection zones
	Protection zones of natural water accumulation
	Natural resources
	Sources of ground and natural mineral waters
	Water bodies used for fish and poultry farming
	Water bodies used for recreation
	Other water courses, bodies (both natural and man-made)
Biotic component of environment	First zone of a national park and protected landscape area
	Second zone of a national park and protected landscape area
	Third zone of a national park and protected landscape area
	Fourth zone of a national park and protected landscape area
	National nature reserve
	National natural monuments
	Nature reserve
	Natural monuments
	Significant landscape components
	Temporarily protected areas
	Nature parks
	Territorial systems of ecological stability
	Protection forests
	Other forests
	Tree monuments, their groups and avenues of trees
	Other areas without special protection
NATURA 2000	Bird protection area
	Area of European significance
Air	High polluted air quality (average annual air pollution PM10 exceeds permitted air quality standards 40 μg/m^3)
	Considerably polluted air quality (average annual air pollution PM10 achieves values between 31 and 40 μg/m^3)
	Negligible polluted air quality (average annual air pollution PM10 does not exceed value of 30 μg/m^3)
Cultural heritage	Area of planned spatial development with protection zones/heritage zones
	Area of planned spatial development without protection zones/heritage zones

are classified into the categories of hazard group and the categories of the asset group. Individual categories then include elements, to which appropriate index values are assigned. The index values consider their hazardousness (in case of hazard group elements) and vulnerability (in case of the asset group elements). The structure of the catalogue of hazard and asset groups is shown in Fig. 2.

Asset group elements

On the basis of complex environmental analysis environmental elements were classified (Allaby, 2000) into the individual categories of the asset group (see Table 1). These elements are classified with respect to land use.

Hazard group elements

On the basis of complex analysis of the environmental aspects for spatial development, aspects were classified (Council Directive, 1985) into the individual categories of the group of threats (see Table 2).

T a b l e 2. Hazard group elements.

Categories	**Elements (IH)**
Emissions into air	Mobile sources of air pollution – high traffic density (e.g., highways, main roads, urban areas and other frequented stretches)
	Mobile sources of air pollution – low traffic density
	Stationary sources of air pollution – particularly large combustion sources
	Stationary sources of air pollution – large combustion sources
	Stationary sources of air pollution – medium combustion sources
	Stationary sources of air pollution – small combustion sources
Release of substances to water	The management of waste or mine water containing particularly hazardous harmful substances
	The management of waste or mine water containing hazardous harmful substances
	The management of waste or mine water contaminated by the radioactive substances
	The management of waste or mine water containing no harmful substances
	The management of oil substances, particularly hazardous substances, radioactive emitters and radioactive wastes
Release of substances to soil	The management of particularly hazardous harmful substances
	The management of hazardous harmful substances
	The management of radioactive substances
	The management of fertilizers and chemical spraying
Emitting of energies	The management of waste water containing waste heat
	Operation of facilities emitting radiation hazardous to health
	Operation of source noise or vibration
Waste production	Hazardous waste production
	Municipal waste production
	Inert waste production
	Production of biodegradable waste

The above list of categories and elements of the environmental aspects for spatial development (Table 2) should be considered only as a framework because in the context of spatial development a number of specific environmental aspects can occur. On this basis, it seems appropriate to create an international publicly accessible register of spatial development environmental aspects in which all environmental aspects related to spatial development were implemented by authorities (e.g. ministries involved). Data from the register would be used as a free accessible database to all the professional bodies involved in the issue of environmental impact assessment for spatial development.

Register of environmental aspects for spatial development should include basic data relating to environmental aspects of the spatial development elements. These data should be a functional component of spatial development, a specific element of spatial development, the category of environmental aspect, environmental aspect (activity or element), specific pollutants and the legislation relating to that aspect.

Coefficients

The consideration of variable parameters (e.g. scope, frequency and probability) elements presented above is used as coefficients. These coefficients have a regulatory function of possible variations in the hazard or vulnerability assessed elements (e.g. the increasing hazardousness of the element of spatial development in relation to the frequency of hazardous substances and waste management) and ensures more accurate outcomes in determining the levels of hazards and vulnerabilities in the individual categories of threat and asset groups. The coefficients are aimed to increase the levels of particular categories according to the current state of variables. The coefficients may be divided into two categories according to their relation to groups of hazards and assets as follows:

- Coefficients related to the group of threats
  - Water or soil pollution burden (C_{WS})
  - Frequency of energy emitting (C_E)
  - Frequency of hazardous substances management and waste management (C_P)
- Coefficients related to the group of assets
  - Level of damage to the area of spatial development (C_D)

Relations defining assessment process of algorithm

On the basis of determination of vulnerability and hazard of group's assets elements and threats and the definition and evaluation coefficients can proceed to relations defining an algorithm assessment process. These relations are a key element in the function of the algorithm and consist of the relations for setting the levels of vulnerability and hazardousness and relations for determining the level of potential risk.

Determination of the level of vulnerability and hazardousness

In the following part of contribution are defined relations that are the basis for calculating the level of vulnerability (L_A) for each category of asset groups and levels of dangerousness

(L_H) for each category of threat groups. Defining formulas is realized by using simple mathematical operations. The level of vulnerability and dangerousness of each category will always be the result of the maximum calculated index values initiated by elements belonging to the category and the relevant coefficients – see formula (1). For each category the following formulas were defined:

Categories of the asset group

- Vulnerability level of category 'soil medium'

  $$L_{A(S)} = I_S^{\max} \cdot C_D$$

- Vulnerability level of category 'water medium'

  $$L_{A(W)} = I_W^{\max} \cdot C_D$$

- Vulnerability level of category 'biota'

  $$L_{A(B)} = I_B^{\max} \cdot C_D$$

- Vulnerability level of category 'NATURA 2000'

  $$L_{A(N)} = I_N^{\max} \cdot C_D$$

- Vulnerability level of category 'air medium'

  $$L_{A(A)} = I_A^{\max} \cdot C_D$$

- Vulnerability level of category 'cultural heritage'

  $$L_{A(K)} = I_K^{\max}$$

Categories of hazard group

- Hazardousness level of category 'emissions to air medium'

  $$L_{H(A)} = I_A^{\max}$$

- Hazardousness level of category 'release of substance to water medium'

  $$L_{H(WM)} = I_{WM}^{\max} \cdot C_{WS} \cdot C_P$$

- Hazardousness level of category 'release of substance to soil medium'

  $$L_{H(SM)} = I_{SM}^{\max} \cdot C_{WS} \cdot C_P$$

- Hazardousness level of category 'emitting energy'

  $$L_{H(E)} = I_E^{\max} \cdot C_E$$

- Hazardousness level of category 'waste production'

  $$L_{H(P)} = I_P^{\max} \cdot C_P$$

Determination of the level of potential risk

On the basis of defining relations for each category of asset groups and threats can proceed with a single defining relation for the calculation of the level of potential risk. Level of potential risk will be calculated within the assessment for interaction of each category of asset groups with each category of threats. The formula for calculating is based on formula (2), which reflects a general platform of risk calculation (Rehak, 2012).

$$R = P \cdot RI \tag{2}$$

where R is the risk level, P is the probability, RI is the range of impact.

The first essential factor in the calculation of the potential risk level is the probability of environmental damage due to spatial development. For determining, the key was made, based on judgement that the probability of adverse events (i.e. damage to the environment) is the highest when interacting most vulnerable and the most dangerous categories, i.e. if the value $L_A = 3$ and $L_H = 3$, then the highest probability and vice versa if the value of $L_A = 1$ and $L_H = 1$, then the probability is the lowest. This means that the basis for determining the probability is the knowledge of the interaction value (V_I) of the studied categories of asset groups and threats. This value can be obtained through the average level of vulnerability of the asset group category and the level of danger of the threat group category – see formula (3).

$$V_I = \frac{L_A + L_H}{2} \tag{3}$$

The second step is to perform the recalculation of the resulting values to the probability of interaction and ensure the correct mathematical notation, i.e. as a percentage. Through the above-mentioned key, interaction values can be divided into five resulting variants, into five equal probability intervals to their corresponding median values of probability (P_{AH}). This recalculation is done in Table 3.

Table 3. Recalculation of interaction value to probability value.

Interaction value	**Probability at intervals**	**Median values of probability P_{AH} [%]**
1.0	<0;20>	10
1.5	(20;40>	30
2.0	(40;60>	50
2.5	(60;80>	70
3.0	(80;100>	90

This method of recalculation, while ensuring that the probability never reaches the limit values, i.e. 0 and 100%, because of their practical feasibility is quite impossible. Based on all the above procedures and conditions (i.e. set keys) formula (4) can be determined, whereby it is possible to convert all values of interaction (V_I) into the values of probability (P_{AH}).

$$P_{AH} = V_I \cdot 0{,}4 - 0{,}3 \quad (4)$$

whereas $P_{AH} \in \langle 0{,}1;0{,}9 \rangle$.

The second factor in the calculation of the level of potential risk is the range of the impact of spatial development on the environment or the potential extent of environmental damage due to spatial development. In determining the range of impact can be assumed, that in case of negative interaction of the asset group category with threat group category, will be harmed in the category of the asset group (such as damage due to substance release into the soil). At the same time it is evident that the higher vulnerability of the asset group category will then be in direct proportion higher by consequence of damage and vice versa. This formula can be expressed as (5).

$$RI = L_A \quad (5)$$

Based on the above, instead of range of impact, the level of vulnerability of the asset group category can be substituted into the relation for calculating the potential risk level. The resulting formula (6) for the calculation of the potential risk level then has the following notation.

$$R_{AH} = P_{AH} \cdot L_A = \left(\frac{L_A + L_H}{2} \cdot 0{,}4 - 0{,}3 \right) \cdot L_A \quad (6)$$

where R_{AH} is the risk level of damage of the asset group category by influence of hazard group (e.g. environmental damage influence of environmental aspect for spatial development), L_A is the level of vulnerability of the asset group category (e.g. environmental compartment), L_H is the level of hazardousness of threats group categories (e.g. environmental aspect for spatial development).

As already mentioned, the level of potential risk will always be calculated separately for interaction of each asset group category with each threat group category. On this basis, into the formula (6) were substituted variables, which were already defined 21 formulas. With this clarity, a formula for calculating the potential risk level of soil medium damage due to release of substances into the soil is presented in formula (7).

$$R_{S\_SM} = \left(\frac{L_{A(S)} + L_{H(SM)}}{2} \cdot 0{,}4 - 0{,}3 \right) \cdot L_{A(S)} \quad (7)$$

where R_{S_SM} is the potential risk level of soil medium damage influence of substance release to soil, $L_{A(S)}$ is the level of vulnerability of soil medium category, $L_{H(SM)}$ is the level of hazardousness of substance release to soil category.

Spatial development impact matrix

The final risks of damage of population, technical infrastructure and the environment caused by the intended spatial development are in the final phase of assessment demonstrated in the spatial development impact matrix (see Fig. 3).

SPATIAL DEVELOPMENT IMPACT MATRIX		**Potential Negative Aspects of Spatial Development**						
		A_A	A_W	A_S	A_R	A_X	A_E	A_P
Population	Health State							
	Mental State							
	Residential and Recreational Areas							
	Livestock							
	Cultural Heritage							
Technical Infrastructure	Water Supply System							
	Electric Power Supply System							
	Gas Supply System							
	Heat Supply System							
	Public Communication Networks System							
	Waste Waters and Waste Management System							
Environment	Soil Environment							
	Water Environment							
	Biotic Component of Environment							
	NATURA 2000							
	Air							

Fig. 3. Spatial development impact matrix.

A_A – Emissions into air
A_W – Release of substances to water
A_S – Release of substances to soil
A_R – Exploitation of raw materials and natural resources
A_X – Exploitation of energy
A_E – Emitting of energies
A_P – Waste production

Note: The cross-hatched field signals that the given aspect and category are not related and therefore the level of risk is not determined for this relation.

The outcome of the assessment process will be the matrix presenting the potential level of risk for population, infrastructure and the environment caused by intended spatial development. Such a risk will be classified into three categories, which for the purpose of the method is a sufficient distinguishing capability.

The description of individual risk categories and the determination of acceptability of potential risk as well as measures to be taken (i.e. the recommendations which should be followed by the assessor) are as follows:

- **The A category of risk level:** Spatial development indicates a low potential risk of damage to the environment in the assessed area (the risk is acceptable). Even potentially highly hazardous elements may be located in the given area when standard safety measures are followed. This category of risk is a necessary prerequisite for building new industrial facilities.
- **The B category of risk level:** Spatial development indicates an increased potential risk of damage to the environment in the assessed area (it is necessary to reduce such a risk). It is not suitable to carry out the planned spatial development in the given area. It is recommended to look for another area or modify the spatial development so that it does not cause damage to the environment. At the same time, it is recommended to reassess the planned spatial development and possibly replan it.
- **The C category of risk level:** Spatial development indicates a high potential risk of damage to the environment in the assessed area (the risk is unacceptable). This category indicates that it is most probable that the planned spatial development will cause an extensive and serious damage to the environment in the given area. Therefore, it is recommended to not only look for another less vulnerable area, but also thoroughly check the range and level of hazard of the planned spatial development.

Software support for spatial development impact assessment

A significant application support for assessment of safety of spatial development is a developed software tool for spatial development impact assessment. The first part of the software tool is public and contains basic information about the application and the entry of potential users in the authenticated section for the purpose of the evaluation process. A software tool is located on the Web address at <http://fbiweb.vsb.cz/sdia>.

The second part of the software tool includes the process of evaluation, which is located in the authenticated section of the application (see Fig. 4). This section is secured to prevent access to undesirable persons. Specified users receive relevant login and password upon request from the administrator. The section consists of a user and an administrator setting. The user interface includes evaluation forms, the results in the form of matrix of spatial development impacts and final protocols from the evaluations.

Case study

This part of article presents a case study aimed at evaluating the environmental safety of spatial development for the hazardous waste incineration plant planned to situate into three

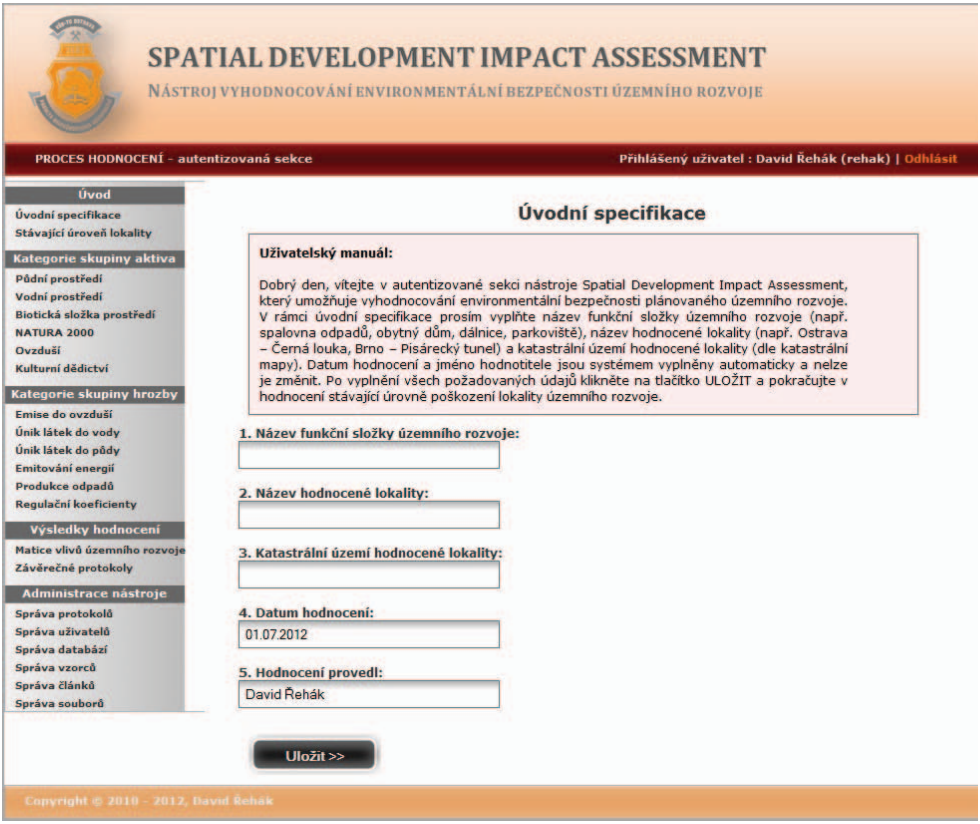

Fig. 4. Authenticated section of software tool for spatial development impact assessment.

different interest areas located in the Moravian-Silesian Region (Řehák et al., 2011c). Finally, the results are presented, and suitable measures are proposed to reduce the potential risks of the intended spatial development.

Description and results from analysis aimed at the selected functional component of spatial development

Functional component of spatial development, which was selected for the case study, is the high capacity incineration plant of hazardous waste. Detailed specifications are as follows:

- Planned activities: loading, storage and incineration of hazardous waste
- Incineration plant capacity: 15 tons/day (1 rotary furnace)
- Accepted waste: solid, soggy, liquid
- Kind of accepted waste: industrial hazardous waste, waste from health and veterinary care
- Method of waste dosing: grab, ladles, nozzle

Based on the analysis, specific negative environmental aspects which were subsequently entered into the catalogue of hazard and asset groups were evaluated for the above functional components of spatial development (see Table 4).

T a b l e 4. The results of analysis of the functional components of spatial development.

Categories	**Elements (I_H)**	**Initiation of elements**
Emissions into air	Mobile sources of air pollution – high traffic density (e.g. highways, main roads, urban areas and other frequented stretches)	☐
	Mobile sources of air pollution – low traffic density	☐
	Stationary sources of air pollution – particularly large combustion sources	☑
	Stationary sources of air pollution – large combustion sources	☐
	Stationary sources of air pollution – medium combustion sources	☐
	Stationary sources of air pollution – small combustion sources	☐
Emissions into air to water	The management of waste or mine water containing particularly hazardous harmful substances	☐
	The management of waste or mine water containing hazardous harmful substances	☐
	The management of waste or mine water contaminating radioactive substances	☐
	The management of waste or mine water containing no harmful substances	☐
	The management of oil substances, particularly hazardous substances, radioactive emitters and radioactive wastes	☑
Release of substances to soil	The management of particularly hazardous harmful substances	☑
	The management of hazardous harmful substances	☑
	The management of radioactive substances	☐
	The management of fertilizers and chemical spraying	☐
Emitting of energies	The management of waste water containing waste heat	☐
	Operation of facilities emitting radiation hazardous to health	☐
	Operation of source noise or vibration	☐
Waste production	Hazardous waste production	☐
	Municipal waste production	☑
	Inert waste production	☑
	Production of biodegradable waste	☐

Description and results from analysis of selected area of interest

For the purpose of verification of tool for Spatial Development Impact Assessment and possible links to GIS, area of interest situated in the Moravian-Silesian Region, in the south part of the regional city of Ostrava, close to the industrial zone Hrabová was selected (see Fig. 5). This area is also located close to the highway, so it is relatively easily available. For a more accurate idea of the location of the object, two buffer zones at a distance of 500 m and 1 km around the facility were created. The nearest residential buildings are to the edge of 500 m of buffer zone. Incinerator occupies an area measuring about 150×220 m.

Fig. 5. The area of interest in the map documents.

On the basis of this analysis, the area of interest was identified by the occurrence of individual elements of the environment that may be in the realization of the intended spatial development damaged. This information was then entered into the catalogue of hazard and asset groups (see Table 5).

The results of spatial development impact assessment

Only after entering information into the catalogue of hazard and asset groups is it possible to assign the corresponding index values (I) to initiated elements (i.e. the user-checked elements). These values were in the creation of spatial development impact assessment tool set by selected expert reviewers from the Czech Republic. Index values for the category of the asset group, however, are known to the user after marking the area of interest into a GIS, as this GIS is linked to the database of catalogue of hazard and asset groups.

T a b l e 5. The results from the analysis of the area of interest.

Categories	Elements (I_A)	Initiation of elements
Soil environment	Arable soil	☐
	Hop-field and vineyard	☐
	Garden	☐
	Orchard	☐
	Meadows and pastures	☑
	Non-agricultural land of agricultural land resources	☐
	Lands with stands of green vegetation	☐
	Developed areas and roads	☐
Water environment	Sources of drinking water and their first level protection zones	☐
	Water sources second level protection zones	☐
	Protection zones of natural water accumulation	☐
	Natural resources	☐
	Sources of ground and natural mineral waters	☐
	Water bodies used for fish and poultry farming	☐
	Water bodies used for recreation	☐
	Other water courses, bodies (both natural and man-made)	☐
Biotic component of environment	First zone of a national park and protected landscape area	☐
	Second zone of a national park and protected landscape area	☐
	Third zone of a national park and protected landscape area	☐
	Fourth zone of a national park and protected landscape area	☐
	National nature reserve	☐
	National natural monuments	☐
	Nature reserve	☐
	Natural monuments	☐
	Significant landscape components	☐
	Temporarily protected areas	☐
	Nature parks	☐
	Territorial systems of ecological stability	☐
	Protection forests	☐
	Other forests	☐
	Tree monuments, their groups and avenues of trees	☐
	Other areas without special protection	☑
NATURA 2000	Bird protection area	☐
	Area of European significance	☐
Air	High polluted air quality (average annual air pollution PM10 exceeds permitted air quality standards 40 μg/m3)	☐
	Considerably polluted air quality (average annual air pollution PM10 achieves values between 31 and 40 μg/m3)	☑
	Negligible polluted air quality (average annual air pollution PM10 does not exceed value of 30 μg/m3)	☐
Cultural heritage	Area of planned spatial development with protection zones/heritage zones	☐
	Area of planned spatial development without protection zones/heritage zones	☐

Consequently, it was possible to proceed to the calculation of the coefficients (*C*), which consisted in putting the selected parameters to preconfigured formulas. The resulting coefficients reflect variable parameters, which are the extent, frequency or probability.

The obtained index values were then put into the formulas to calculate the vulnerability levels for the categories of the asset group (L_A) and the hazard levels for the categories of threat group (L_H). The level of each category was calculated by the multiple of the maximum index value – initiated elements that belong to a given category and the relevant coefficients (see formula (1)).

In the next step, the probability (P_{AH}) of damage of the asset group categories by the effect of group threat categories was determined. Mathematically, the probability of damage was determined by goniometric average level of hazard and the level of vulnerability assessing categories (see formula (3)).

The final step of the assessment process was to determine the level of risk of potential damage to the environment due to the intended spatial development (R_{AH}). The risk level was then determined by the multiple of the level of vulnerability of the group asset category and the probability relevant to the assessed categories of threat and asset groups (see formula (5)). Results are clearly presented in the matrix of spatial development impact (see Fig. 6).

SPATIAL DEVELOPMENT IMPACT MATRIX		Categories of the HAZARD Group				
		A_A	A_W	A_S	A_E	A_P
Categories of the ASSET Group	Soil environment		B_2 (1.47)	B_2 (1.47)		B_1 (1.09)
	Water environment					
	Biotic component of environment	B_1 (0.55)	B_1 (0.62)	B_1 (0.62)		A (0.41)
	NATURA 2000					
	Air	C (1.92)				
	Cultural heritage					

Fig. 6. Spatial development impact matrix (filled).

A_A – Emissions into air
A_W – Release of substances to water
A_S – Release of substances to soil
A_E – Emitting of energies
A_P – Waste production

Note: The cross-hatched field signals that the given aspect and category are not related and therefore the level of risk is not determined for this relation.

The resulting levels of potential risk of damage of interest area due to spatial development are divided into four categories:

- Category A (0.1 to 0.45) – acceptable risk
- Category B1 (0.46 to 1.20) – risk should be reduced

- Category B2 (1.21 to 1.75) – it is necessary to reduce the risk
- Category C (1.76 to ∞) – unacceptable risk

Visualization of results of the assessment of environmental safety in GIS is demonstrated on the environmental aspect of spatial development 'Waste Production' (see Fig. 7).

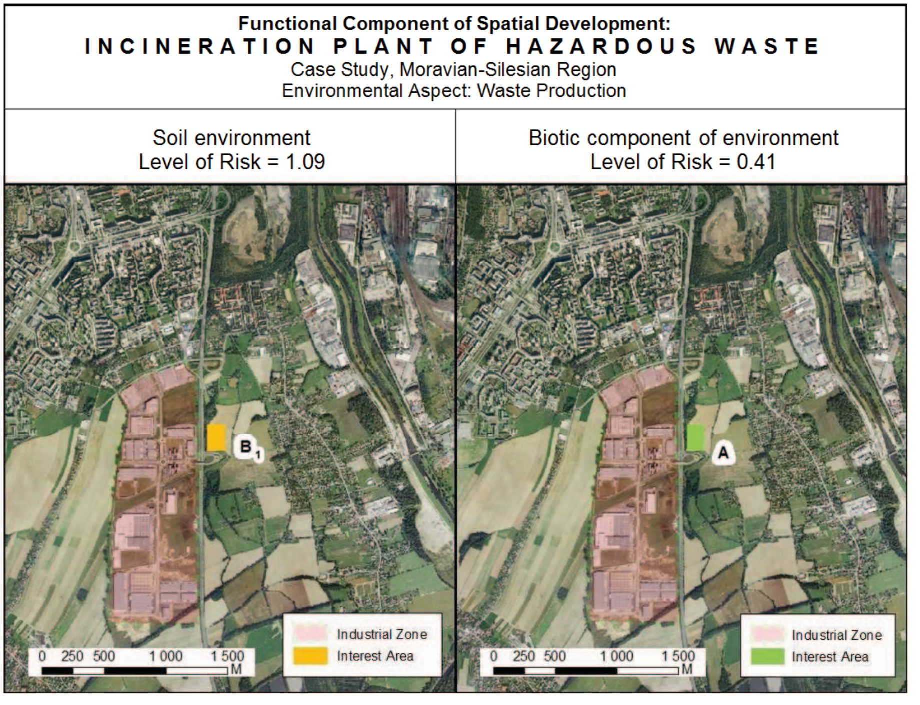

Fig. 7. Visualization of results in GIS.

The aim of the presented case study was to evaluate environmental safety of spatial development for the planned location of the hazardous waste incinerator in the selected area of interest which was located in the Moravian-Silesian Region in the Czech Republic. Based on the obtained results, the potential risk of damage to the environment due to spatial development can be divided into four categories.

As an acceptable risk (Categories A and B1) can be considered the potential negative impact of the intended incinerator on biotic component of environment, this risk can be further controlled, but it is not a condition of the realization of planned spatial development.

In contrast, the risk that it will be necessary to reduce (Category B2) has been found in the incinerator effect on soil environment. Totally unacceptable risk (Category C) was found in areas of incinerators impact on air. Based on the above, it is recommended either planned spatial development in the area to realize, but in this case, to ensure maximum possible air protection (e.g. using the latest modern technology end-of-pipe) or planned spatial development in the area do not realize and rather to make look for the better interest territory.

Conclusion

The basic premise of social, technical and environmental safety of spatial development is a preventive assessment of all possible risks of the planned spatial development and then minimization prior to the realization of spatial development (Kozlowski, 1990). Just like in the case with a number of technical fields here can be used to improve the process, also various methods and tools for assessing impacts. In the analysis of technological risks, these tools currently present the best way for the prevention of activities with a negative impact on the population or on the environment (Bartlova, Balog, 2007; Senovsky et al. 2009). For this reason, it is an unquestionable fact a need to develop and apply a similar impact assessment tool for spatial development.

Based on the above mentioned and also existing knowledge in the field of methods and tools for impact assessment, it is proposed to ensure the safety of spatial development by using a simple algorithmic procedure that appears to be very useful for several reasons. Until now, there is no clear and universal tool to evaluate the impacts of spatial development on the population, technical infrastructure and the environment in relation to the intended land use plan. The universality of the algorithm is highlighted by the fact that it can be easily optimized and used in different countries, even those in which there are different legal rules and the value of territory planned for the development is quite variable. A relevant fact is that the presented tool for social, technical and environmental safety of spatial development is not prescriptive mechanism, but can be used as an informative tool recommending to evaluators if the planned spatial development in the area is suitable to realize or not.

Easy applicability of this algorithm in practice supports the presented software tool, which is available online through the Web interface. This tool can be updated or modified at any time, depending on the required outputs (Rehak, 2011). Modified version of the method presented in this article is currently used successfully, for example, by Army of the Czech Republic for the assessment of the impact of military training activities on people and the environment located close to military training areas (Rehak et al. 2010). Possibilities of modification and use of methods for the civilian sector are currently being discussed with the Fire Rescue Service of the Czech Republic.

Acknowledgements

The article is connected to a research, development and innovation project called 'Security of the population – crisis management', identification code VF20112015018. Project funding has been provided by the Ministry of Interior of the Czech Republic as part of its program 'Security Research for the Needs of the State 2010-2015'.

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Ekológia (Bratislava) Vol. 32, No. 2, p. 242–247, 2013
doi:10.2478/eko-2013-0020

WATER FLOW MODEL FOR THE HARRIER BASIN, KURDISTAN OF IRAQ

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Abstract

Sharif A.J., Elias Z.R., Omar M.F.: Water flow model for the Harrier basin, Kurdistan of Iraq. Ekológia (Bratislava), Vol. 32, No. 2, p. 242–247, 2013.

The study includes computer topographic and morphologic simulation of water flow produced using a watershed modelling system that uses hydrologic and physical data from the study area. The DEM module, TIN module, Map module and Hydrologic module were used in this study. A land use data, a soil data and rainfall data were used to produce a curve that illustrates quantity of water flow versus time of water flow across the Harrier basin. The calculated water loss rate can be attributed to a number of factors such as joints, faults, bedding and land use (agriculture and forest). Land use and soil characteristics are both important factors affecting water flow rates. The climate in the Harrier basin is semi-arid. Simulated flow data indicate that the top flow rate is 32 m^3/s and that water can reach to the basin outlet in 3 hours and 10 minutes.

Key words: Harrier, GIS, basin, valley, quantity of flowing water, flow time, water loss.

Introduction

A model is defined as a simple compound system in which the behaviour of this system is represented by number of equations with logical aspects and relations between the variables to predict the required results (Clarke, 1973). The aim of such a model is to optimally understand watershed performance and the effect of variations as well as to serve as a suitable tool designed to get specific data concerning water flow (Jianyao, 1998). Channels and channel starting points are mapped as those grid cells where the support area threshold is exceeded. This procedure has been widely used and is implemented in the Arc Info grid. An important question associated with this method is what support area threshold to use? A basin's hydrology depends on its geomorphic form as well as hill slope. Channel and ecological processes are active at different spatial and temporal scales (Vivoni et al., 2007). The study includes computer topographic and morphologic simulation of water flow produced using a watershed modelling system (WMS) that uses hydrologic and physical data from the study area. The WMS includes powerful tools designed to automate the modelling process. These tools include automated basin delineation, geometric parameter calculation, GIS overlay computation and cross-section extraction from terrain data. The aim of this paper is to focus on creating a hydrologic module and digital elevation models (DEMs) in a GIS environment as well as to learn how the data can be used in conjunction with a WMS to run lumped-parameter hydrologic models. This type of process requires the use of physical characteristics such as curve of hydrograph, rate of water loss and the time needed to reach to the mouth of the Harrier basin area of 20.9 km^2. Elevation data can be represented digitally in many ways, including a grid model, where elevation is estimated for each cell in a regular grid, a triangular irregular network and contours (James, Linda, 1997). The representation of the DEM as a grid is quite common, as this format lends itself well to computer computations. These techniques include DEMs, which can be used to extract flow direction and Arc View. GIS techniques were used to define the relationship between topography and state variables of geoprocesses (Tong, Chen, 2002); while WMS techniques helped to calculate water flow through the valley, as well as identify the land use and soil type in the area.

Methods

GIS programmes and elevation data in a grid format can be used to delineate drainage basins, create stream networks and compute drainage basin data. Once computed, several important variables, such as area, slope and run-off distances, can be determined for hydrological analysis. A DEM can be used to determine the hydrologic parameters of a watershed such as slope, flow accumulation, flow direction, drainage area delineation and stream network. TINs were derived from a contour map. Then, the (DEM) and Map Module were used to produce a digital map of the Harrier Basin. The digital map of the basin is three-dimensional.

The TIN and Hydrologic Module were used to produce a water flow curve for the study area and to calculate flow time. The curve requires the integration of four layers: (1) digitized 3-D contour map, (2) digitized land use map five groups (Table 1), (3) digitized soil coverage map (three groups A, B, and C (Table 2) and (4) daily local rainfall data. Land use and soil classes were also used in the computation of run-off use of the SCS Curve Number Method to calculate water loss. Supplemental data were collected on-site during the winter season (Fig. 1).

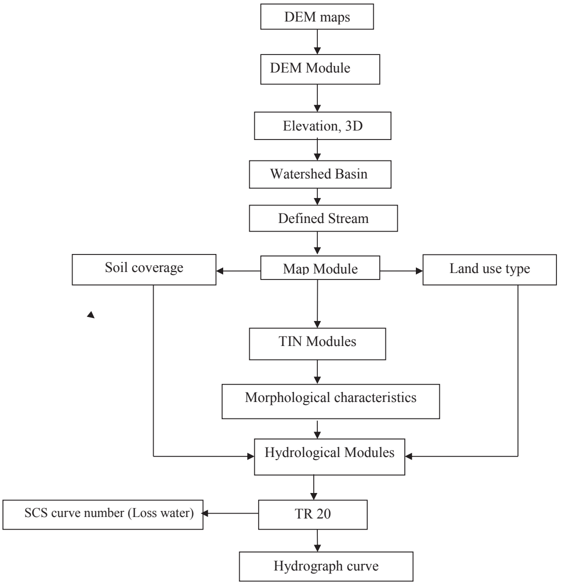

Fig. 1.WMS flow chart.

Description of study area

Stream flow is one of the main manifestations of hydrologic conditions in drainage basins. Because streams are the foundation from which other information is georeferenced or derived, the quality of the original stream data influences the quality of subsequent data layers. Biological, physical and chemical conditions, including fish abundance, habitat types and dissolved oxygen concentrations, can be georeferenced to a stream layer. The study area lies in the higher fold zone in northern Iraq (Kurdistan of Iraq) where the mountain affects the shape of the stream in the middle and southern parts of the study area (Omar, 2005). Basin slope is 1.2711 m, mean elevation is 477.08 m and sinuosity is 9.8 m (Table 1). Differences in stream slope manifest themselves in fluvial processes on hill slopes and in stream channels. It is important to properly map the physical extent of a stream and its tributaries within a study area. Figure 2 is an elevation map of the study area. The stream rises to flow at an elevation of 1200 m in the Harrier mountains. All elevations (1100, 1000, 900 and 800 m) are located in the southern slope of this mountain range because this is where geomorphic processes can be best observed (denudation, erosion transport). Slope stability shown in these elevations in different failure types toppling, plane sliding and rock fall (Barzani, 2008). A break in the slope occurs at an elevation of 700 m due to gully erosion. The down-slope area is found at elevations of 600, 500 and 400 m. At these locations, sediments appear to yield to fluvial transport process.

T a b l e 1. Morphological characteristics of Harrier basin.

Area (km)	20.9
Average slope of basin (m/m)	1.2711
Average overland flow distance (km)	1003.49
Maximum flow gradient (m/m)	0.3578
Length of basin (km)	20 425.8
Maximum flow distance (m/m)	27 968.88
Sinuosity (msl/l)	9.8
Average elevation of basin (m)	477.08
Maximum stream length (m)	22 450.62
Maximum stream slope (m/m)	0.0896

T a b l e 2. Types of land use in Harrier basin.

Location	**Shape of surface**	**Type of land use**
Mountain	Dip slope	Little forest
Hill slope	Variability	Bad land
Harrier town	Sub-variability	Urban area
Batas	Sub flat	Forest
Plain	Flat	Agricultural

T a b l e 3. Soil coverage in Harrier basin.

Layer	**Location**
A	Batas, hill slope
B	Plain
C	Harrier Mountain

Results

Water flow is concentrated in channels, hence the drainage area contributing to each point in a channel may be quantified, while on hill slopes, flow is dispersed. The ‘area’ draining to

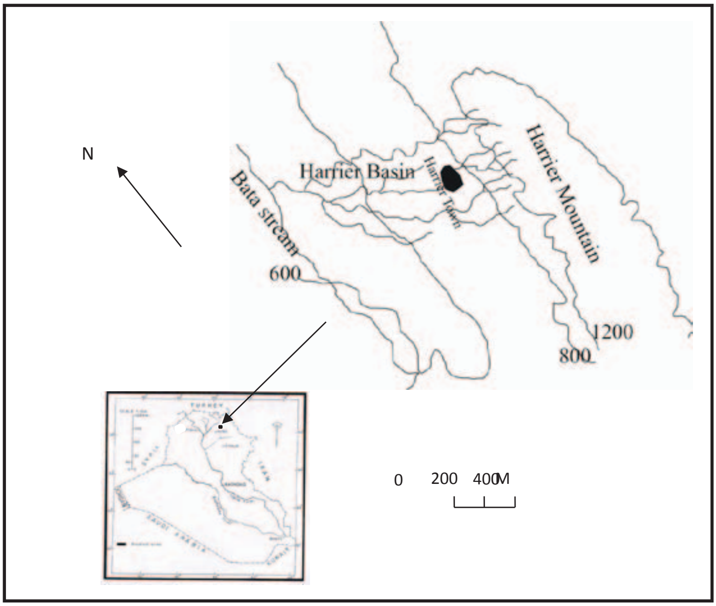

Fig. 2. Location of the study area in Iraq.

a given point is zero because the width of a flow path to a point disappears (Fagherazzi et al., 2004). In Table 3, the watershed modelling programme used physical characteristics such as maximum flow slope (0.3578 m/m) and total length (20 425.8 m). The time of concentration for the study area was calculated by the modelling programme as 3.5 hours and 5 minutes. A long storm period produces significant flooding at the basin outlet, which increases erosion (a form of sediment transport) throughout all 3 hours. Figure 3 shows water flow versus time, starting from the Harrier Mountains to the point of confluence with Bata Stream (basin outlet). The quantity of water flow changes from the axial area of the Harrier Mountains, as it is fed back to the sub stream. The water flow rate starts at 5 m^3/s in the Harrier Mountains at 1 hour and a half, and increases in the middle section of the basin to 32 m^3/s at 2 hours and a half. This is because more sub streams affect Harrier Stream.

Overland flow and maximum flow distance are important for fluvial processes in the case of gully erosion. A large rainfall rate can overcome the soil's infiltration rate during a storm event (Solyom, Tucker, 2004). The rate of water loss during a storm is 47.05%. This is due to four factors – joints and faults in the Harrier anticline as well as soil type and land use in the middle and southern parts of the basin. In the middle and southern parts of the basin, agriculture plays a role and the soil type is represented by two crops (A and B). All of the above factors lead to water loss in two areas – the first is the ground and second is the basin surface, which is used by agriculture.

As erosion advances, flood peaks increase in magnitude and decrease in response time, suggesting higher basin sensitivity to rainfall. Fluvial erosion leads to steeper slopes along the Harrier anticline channel interface, which affects the resulting hydrograph. Major soil erosion occurs in Layer C in the Harrier Mountains – called gully erosion. Other factors such as slopes, joints and faults featuring little vegetation also lead to the loss of this layer.

Discussion

Short water flow times are important for other types of studies – ones that deal with hazard flood maps. An entire event, from initial flow to drought, might take no more than a few hours. The town of Harrier will be in danger if the depth of rainfall is heavy because it is located in the south limb of Harrier mountain. This danger will be in the sub-basin because it flows from elevation 1200 to 800 m and it is short.

The variability surface with little forest is occurring in these elevations and more rainfall flowed from this elevation in the shape of gully erosion. Activity fluvial geomorphology is shown with feature of slope stability; however, the affect of fluvial process has appeared on the road of Harrier town during and after the storm such as sediment and rock. Lost forest in the Harrier Mountain and layer C soil are field back to global climate changes and human used these forests for life. So this cannot be safe from other processes such as rock fall and sediment yield.

Conclusion

The peak flow hydrograph, shape of hydrograph and time of peak flow are the most important parameters to predict flow hydrograph of flood. Morphologic, soil type, land use and rainfall data

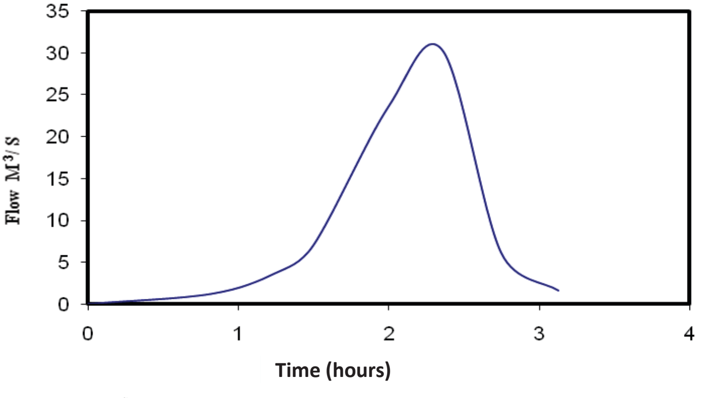

Fig. 3. Water flow versus time.

for the Harrier Basin were successfully used to analyse water flow rates. The run-off coefficient and peak discharge were calculated as well. Run-off and soil loss data for small drainage basins are becoming increasingly important as concerns about surface water quantity increase (Fig. 4). Water quantities in the Harrier Basin have changed over the last few years due to insignificant rainfall (one to three months).

The 3-D model provides reliable data estimates. The Harrier basin has flowing water in the winter and is dry in the summer. The relationship between rainfall and run-off coefficients for the Harrier basin was shown by the infiltration process.

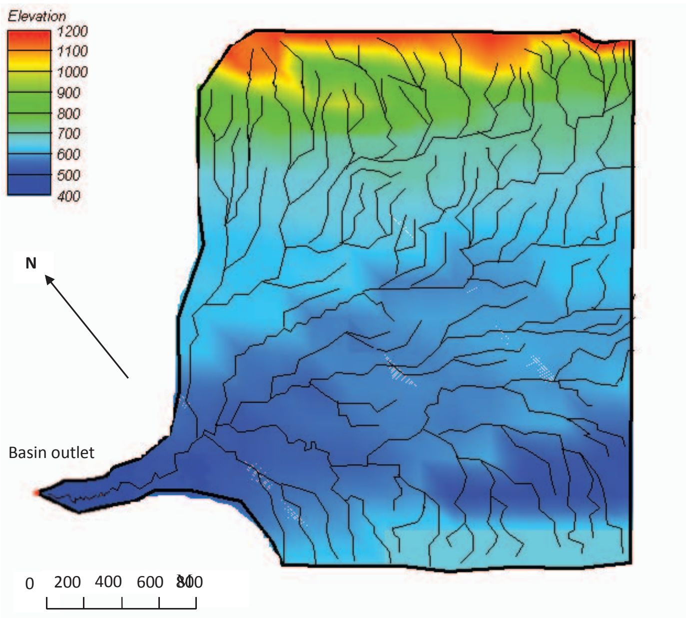

Fig. 4. Drainage basin with elevations.

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Ekológia (Bratislava) Vol. 32, No. 2, p. 248–261, 2013

doi:10.2478/eko-2013-0021

THE EVALUATION OF ECOLOGICAL FACTORS AFFECTING ENVIRONMENTAL FUNCTIONS OF THE SOILS IN AREA OF TRADITIONAL AGRARIAN STRUCTURES

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Abstract

Krnáčová Z., Hreško J., Kanka R., Boltižiar M.: The evaluation of ecological factors affecting environmental functions of the soils in area of traditional agrarian structure. Ekológia (Bratislava),Vol. 32, No. 2, p. 248–261, 2013.

Cultural landscape can be seen as a result of hundred years of founding and sensitive cultivation of landscape structures respecting natural conditions. Specific geomorphological, climatic as well as social conditions enabled the conservation of original agrarian landscape structures mainly in the marginal regions of Slovakia. They are created by mosaic structures of extensively used small-scale landscape elements of permanent agricultural and arable land. An example of traditional agrarian way of using is foothill meadow-grazing landscape of the village Liptovská Teplička. By using the traditional extensive maintenance of the agricultural landscape, optimal environmental characteristics of soils were preserved. These were modified to some extent by the way of using and management. The submitted contribution is focused on the following:

- Indication of environmental characteristics of soils
- Quantification of the influence of chosen ecological factors on these environmental functions

Seven research localities representing main types of the traditional landscape maintenance were chosen for needs of the research of soil and environmental conditions in a relation with the way of using the land and management. In given localities, we chose 21 sampling sites for secondary landscape structure (according to the legend of project Corine Land Cover, 2000), geological, soil, physical, biochemical and chemical conditions evaluation.

Environmental functions indication was assessed in the following way: by assigning an amount of organic carbon (C_{ox}) in a standard way (Fiala et al., 1999) for production functions, by assigning a ratio of granular fractions (pipetting method according to Novák) for retention functions. Buffering functions were evaluated potentiometrically by assigning an active soil reaction of pH (H_2O) and exchange reaction of pH (KCl) in a soil. Highest values of C_{ox} in the Ap horizon (7.67–6.62%), as well as pH of the soil environment (pH/KCl 7.26–7.21, pH/H_2O 7.69–7.68) were assigned to anthrosolic and cultisolic rendzinas of extensively used grasslands. On the contrary, the lowest monitored values of organic matter C_{ox} (2.51–2.53%), as well as pH of the soil environment (pH/KCl 4.81–5.21) (pH/H_2O 5.21–6.19) were indicated for soil subtypes anthrosols of the large fields and lithosol of the extensively used grasslands on non-carbonate substrates. Most favourable production and buffering soil properties were preserved in rendzinas on the carbonate substrates and extensively used meadows. Similarly, this type of soil on limestone used in a form of extensive meadows preserved also the most favourable retention functions according to the stated ratio of granularity fractions.

Quantification of the influence of chosen ecological factors on environmental functions was performed using multivariate statistical methods, specifically principal component analysis (PCA). PCA is an indirect gradient analysis using the linear correlation of data, with a biplot as an output. Closeness of points in ordination graph represents their similarity of composition. The CANOCO (Ter Braak, Šmilauer, 2002) software was used to perform the analysis and to create the graph.

Key words: environmental functions of the soils, traditional agrarian structure, ecological factors, landscape management, Liptovska Teplička.

Introduction

Currently in Central and Western Europe one finds relatively few intact or close-to-nature landscapes. The vast majority of area is occupied by cultural landscape in various state of transformation of the original landscape and with varying degree of its preservation or functionality (Podolák et al., 2011). Cultural landscape can be understood as a result of hundreds of years of establishment and sensitive cultivation of landscape structures respecting the natural conditions. In marginal areas and also here in Slovakia, the original or traditional agrarian landscape structures have been retained due to the specific geomorphological, soil, climatic and social conditions.

An example of a traditional agrarian way of using is a foothill meadow-grazing landscape of the village Liptovská Teplička. The value of these preserved agricultural landscape structures results primarily from the low degree of intensification, high landscape and biological diversity, preserved traditional technological farming practices of tillage and management and preservation of the original environmental soil functions (Dobrovodská, Špulerová, 2011). Extensive forms of use and traditional agricultural technologies determined the preservation and revitalization of the original soil functions. Soil in these agro-ecosystems has in several aspects an important role. First, as an irreplaceable component of landscape, it fulfils a (productive) trophic function for crops and plant communities; then as a component with high capacity regulation, detoxification, hygienic and sanitation importance it fulfils the environmental function – protects other components of the environment and natural resources. In traditional agro-ecosystems, it also fulfils the function of a historical medium, where features of natural processes and human activities history are preserved (Fig. 1).

In the recommendation of the Council of Europe num.8 from the year 1992 (Blum, 1990), individual functions of soils are defined as ecological functions and functions which are related to human activities – technical, industrial and socio-economic functions.

Juráni, 2005 collectively called all functions of soil systems environmental functions, but for the purposes of clarity he divides them into productive and non-productive functions. Productive (trophic) function of soils represents the ability of soils to provide vegetation as well as soil biota with necessary nutrients. Non-productive functions are related to environmental protection, landscaping and revitalization of species diversity, which is an important stabilizing factor for the landscape.

Fig. 1. Surroundings of Liptovská Teplička with traditionally used narrow strip shelves (Photo: J. Hreško).

Our contribution includes an evaluation of the following environmental functions of soils.

- ***Trophic (productive) function of soils*** – is defined (Džatko, 1981) as a measurable level of the main attribute of each soil unit to accept, transform, store and deliver the required amount of water, nutrients and energy for growth and production of plants. Value of production capacity of soils is a function of interaction between abiotic and biotic components of the landscape ecosystem, where substantially the anthropogenic factor also enters in the form of land use and management (Krnáčová, Bedrna, 1994).
- ***Retention (accumulation) function*** – the ability of soil to accumulate rainwater or rising groundwater. Accumulation function of soils in relation to soil water retention has a significantly physical nature, i.e. is a function of the ratio of soil fractions.
- ***Buffering function of soil*** – lies in their ability to reduce the effect of chemical substances and temperature. Emissions of chemical nature, e.g. acidification components, are buffered by base cations present in the soil (Demo et al., 1998). Soil also reduces the impact of atmospheric temperature, which is of great importance in soil overheating. The size of the buffering capacity of soils is affected by grain size ratios, soil organic matter content and significantly also chemistry of the geological subsoil as well as the type of vegetation cover.

The overall aim of the research was focused on the following:

- Indication of selected environmental (trophic, accumulation (retention) and buffering) properties of soils
- Quantification of the impact of selected ecological factors on the environmental functions

Material and methods of the research

Research locality

According to the natural urban catchment regions of Slovakia (Miklós, Hrnčiarová, 2002), the area of Liptovská Teplička belongs to the Spiš region, Poprad micro-region. The area is a part of the Low Tatras National Park (LTNP) and its protection zone.

Administratively, it falls in the Prešov region, Poprad district. It is located in the area of river basin of the Black Váh. The area is designated by the cadastral boundary and takes the intravillan of the town and extravillan with adjacent areas of meadows, pastures, arable land and forests. The total surface area is 9 869 ha, 81% of which are parcels of the forest land fund (FLF), 17.26% agricultural land fund (ALL), of which 16.57% is permanent grasslands (PG), almost 1% is a built-up area and 0.55% water surfaces.

Methodology of the research

There were selected 3–4 sampling sites (21 in total) within the selected research localities, where the following attributes of landscape and soil-substrate conditions were set.

- Analysis of the current land-use from the year 2010, which was interpreted with help of the Basic Maps of the Slovak Republic at a scale 1:10 000 (from years 1992–1993) and ortophotos at a scale 1:5 000 from years 2002–2003 (Ortofotomapa© Geodis Slovakia, s. r. o, 2003; Letecké snímkovanie a digitálna ortofotomapa © Eurosense, s. r. o, 2003). These were verified by the reconnaissance field research in the year 2010. When evaluating the secondary landscape structure, we used the legend created for the Corine Land Cover project from the year 2000 (Feranec, Oťaheľ, 2001, 2008; Petrovič et al. 2009),
- Analysis of geological conditions according to the Regional Geological Map of the Low Tatras (Biely et al. 1992, Biely et al, 1999) at a scale 1:50 000
- Analysis and classification of the soil type, subtype and class directly in the field according to the Morphogenetic Classification Soil System of Slovakia (VÚPOP, 2000; Čurlík, Šurina, 1998).
- For laboratory determination of the granular composition of soils, a pipetting method according to Novak was used. Active soil reaction (pH/H_2O) was determined potentiometrically in aqueous suspension (soil to water ratio 1:2.5) and an exchange soil reaction (pH/KCl) was determined in a leachate of 1M solution of KCl also potentiometrically (ratio of soil to KCl solution 1:2.5). The overall content of organic carbon (C_{ox}) was determined using a standard procedure (Fiala et al., 1999).

Environmental performance indication

We evaluated the production (trophic) soil functions using the organic matter content (C_{ox}) as an indicator, next the buffering soil functions were evaluated according to the parameter of the soil reaction of pH (H_2O) and pH (KCl) and accumulation (retention) characteristics with respect to soil water retention indicated according to the ratio of specified granularity fractions.

Quantification of the impact of selected ecological factors on environmental functions

The objective of the analysis was a quantification of the impact of some ecological factors (impact of geological substrate, management, land use method etc.) on properties of environmental functions. We used a principal component analysis (PCA) for this purpose. It is an indirect linear gradient analysis, whose objective is finding the highest variability data axes. In the output ordination graph we can interpret the proximity of two points (coordinates of individual samples) as their similarity in composition. The analysis and the output graph were created with CANOCO software (Ter Braak, Šmilauer, 2002).

Quantification of the input variables (indicators)

When using input variables while using any statistical software, it is required to use quantitative interval scale variables as input variables. Failure to keep this strict condition may strongly deform the results of analysis. In case of an inevitable use of qualitative indicators, there is a possibility of their requalification to nominal scale variables (quasi quantitative type) which may be used for the analysis. Distinction of variable scale type (Krnáčová, Krnáč, 1999):

- Nominal variables (quasi-quantitative variables),
- Ordinal variables (qualitative variables),
- Interval variables (quantitative variables).

Input data table structure

Data structure in an input table is closely related to quantification, as it allows:

- to quantify information which cannot be quantified directly,
- to quantify ordinal data which cannot be directly used for ecosystem models analysis,
- to modify measured data into standard shapes (multidimensional matrices) suitable for synthesis of various character data sets (data sets describing characteristics of the physical environment, method of land use and other character data).

The most widely used data structure is the following:

$$X(n,N)=\begin{bmatrix} x_{11}, & x_{12}\cdots\cdots\cdots & x_{1n} \\ x_{21}, & x_{22}\cdots\cdots\cdots & x_{2n} \\ & & \\ x_{N1}, & x_{N2}\cdots\cdots\cdots & x_{Nn} \end{bmatrix}$$

set of n variables which are element indicators

N-component sample set

Results and discussion

Diversity of soil-substrate complexes in a wider cadastral area

Knowledge of soil properties on a broader cadastral level provides detailed knowledge about spatial variability of soil cover as a component of the environment. On the carbonate rocks – there are developed moderately to strongly skeletal rendzinas with dark (mollic) humic A-horizon, loamy, humus and moderately deep, which, however, are due to the altitude and rising humidity a subject to leaching of carbonates from the soil profile and change themselves into cambisolic rendzinas and rendzinous cambisols, relatively less productive soils. Typical for steep slopes and sharp backs is modal rendzina, characterized by shallow soil profile which is strongly skeletal and low in productivity. Their presence is bound to the southern part of the model area, the vast complex of dolomitic limestones, respectively Ramsau dolomites of the middle and upper trias in the area of localities Grúň, Skorkovec, Opálené, Kolibisko and Panská Hoľa.

Mineral-rich, non-carbonate substrates such as basalts, andesites and marly shale determine the presence of sandy-loamy to loamy, moderately humus and moderately deep to deep cambisols with low to medium content of skelet, located in the northern part of the area. It is a complex of cultisolic cambisols and modal cambisols, small parts of which are used as terraced fields in the vicinity of the intravillan of Liptovská Teplička.

Mineral-poorer rocks such as light-grey conglomerates, colourful sandstones, siltstone and shales determine the formation of modal cambisols with more acidic soil environment and therefore moderate to low productive soils. On the substrate basis of basalts, andesites and volcaniclastics in the northern part of the area developed andosolic cambisols; locally at steep slopes developed strongly skeletal cambisolic rankers, low productive soils. In the depression parts of the relief including broad backs platforms developed, due to the water stagnation in soil profile, stagnosolic cambisols.

They occur mainly in the northern part area of localities Doštianka, Soľanka, Pod Zálomom. Bottoms of valleys are created by fluvial loamy-sandy and gravelly-sandy sediments, where a relatively narrow range of gley fluvisols, from more skeletal sandy-loamy and low production soils to deep, loamy less skeletal gley fluvisols, also low production as a result of prevailing reducing conditions in the soil environment. In vast areas in the confluence of Ždiarsky brook and Black Váh as well as alongside mentioned streams (Rovienky, Záteplica, Na Váhu) developed typical gley soils. These are soils with gley reduction G-horizont within 50 cm under the surface, in the profile, as a result of high groundwater level, prevail strong reduction conditions. These are soils with low productivity.

At the anthropogenic forms of relief with graded terraces, where rocks were removed by human, developed mostly productive cultisolic rendzinas, rarely cultisolic cambisols. Prevailing in the Nový Diel locality on the substrate of light-grey conglomerates, multicoloured sandstones, siltstones and shales are cultisolic cambisols, less skeletal, moderately productive. The occurrence of terraced fields with developed cultisolic cambisols is further bound with deluvium from clayey and marly shale, less skeletal soils with deeper soil profile in the areas with local names Podvora a Pod Kikulou. There is an extensive occurrence of cultisolic rendzinas at deluviums of Ramsais dolomites and limestones in the southern part of intravillan in the Skorkovec locality. In the close proximity of the intravillan from the northern part, on the substrate of radiolarian limestones are also classified cultisolic rendzinas, and at their deluvias developed cambisolic rendzinas. Figure 2 shows partial abiocomplexes which characterize geomorphological, climatic and soil characteristics processed for the whole cadastral area of Liptovská Teplička.

Selection of research localities

Seven research localities representing basic types of traditional farming landscapes in Liptovská Teplička (Fig. 3) were chosen for the needs of research of soil-ecological conditions in relation to the way of land use and management.

Indication of environmental features

We were evaluating the chosen production, accumulation (retention) and buffering functions according to the set selected soil-substrate parameters, management and land-use patterns in the research localities (LT1–LT7) as follows. As a part of the research, anthropogenic forms of relief (AFR) were also classified. Environmental functions of anthropogenic soils within the forms of anthropogenic relief are not being assessed.

Fig. 2. Partial abiocomplexes.

Fig. 3. Location of research areas within the model area of Liptovská Teplička.

LT1 – extensively used permanent grasslands (PG) mainly used as pastures, with loamy-rocky terraces (2.3537 ha), **LT2** – extensively used mosaic of arable land and PG mainly used as meadows, with loamy-rocky mounds, re-cultivated meadow and re-cultivated arable land (4.1688 ha), **LT3** – extensively used PG with rocky earthed mounds and extensively used PG (meadow) without balks (3.636 ha), **LT4** – extensively used PG alternately mowed or grazed with rocky mounds on the siliceous substrate (3.4507 ha), **LT5** – extensively used mosaic of arable land and PG with loamy terraces (7.122 ha), **LT6** – extensively used mosaic of arable land and PG with loamy-rocky mounds, re-cultivated meadow (3.6838 ha), **LT7** – extensively used PG used mainly as meadows with loamy-rocky terraces (3.1492 ha) (Dobrovodská, Špulerová et al., 2011).

Extensively used pasture with the occurrence of loamy-rocky terraces (LT1)

Cultisols are dominating on the substrate of silicate conglomerates, sandstones and shales with medium skeleton content, which also corresponds with the laboratory set values of pH (H_2O) 5.95 and pH (KCl) 5.02. The measured pH of the soil environment indicates soils with weak buffering system – soils moderately resistant to acidification. The higher proportion of organic carbon C_{ox} 3.71–3.26% is conditioned by the supply of organic substances from excrements of occasionally grazing cattle. The C_{ox} content of the extensively used pastures characterizes these soils as moderately to highly productive. The soil is loamy-sandy with medium skeleton content, what may be interpreted as soils with moderately strong storage capacity regarding the soil water retention. On loamy-rocky terraces a modal ranker was classified with higher content of skeleton, and with slightly acidic soil reaction.

Extensively used mosaic of arable land and permanent grasslands (PG) with loamy-rocky mounds (LT2)

The occurrence of cultisols and cultisolic cambisols is predominant on the substrate of the weathered eluvial clay and marly shale. The set pH/H_2O within the interval 6.19–7.47 indicates soils with neutral soil reaction, which may be interpreted as soils with moderately strong to high buffering system. The organic matter content in the intensively used arable lands and meadows is relatively low, which is indicated by the measured value of C_{ox} within the range 2.51–2.53%. The low value of organic substances is associated also with acidic silicate rock substrate and intensive land use. Soils are loamy; skeleton content is low, indicating soils with good to high accumulation capability to bind soil water.

Extensively used meadow with rocky-loamy mounds and meadow without AFR (LT3)

The prevailing soil subtype is cambisolic rendzina on the substrate of rocky limestone deluviums. The way of use is an extensively occasionally grazed meadow. Soil reaction is neutral to alkaline, conditioned by the presence of carbonates in the soil, pH /H_2O is within the range 7.13–7.69 and pH/KCl within the interval 6.46–7.26. The soils have a high buffering system, interpreting soils as highly resistant to acidification. Organic substances content, indicated by value of C_{ox} is high, within the interval 7.67–6.62%. High proportion of organic matter is conditioned by grass biomass residues and natural organic fertilizers, as well as the carbonate substrate. The soils are moderately to highly productive, a limiting factor is thickness of the soil profile. The soil is loamy. Locally, at the rocky and loamy mounds (AFR), carbonate and lithosolic anthrosols are present on the substrate of rocky mound. Measured pH (H_2O) value is 7.52 and pH (KCl) value is 7.11, which are neutral to slightly alkaline soils, conditioned by carbonate rocks. The C_{ox} value is 5.45%, thus indicating higher value of organic substances affected by the presence of carbonates in the soil and grass biomass residues.

Extensively used permanent grasslands (PG) with rocky mounds on siliceous substrate (LT4)

In this locality a cultisolic ranker is classified on a substrate of loamy-rocky silicate deluvium on siliceous sandstones and shales. Value of pH (H_2O) is 6.02 and pH (KCl) value is 4.94, which are slightly acidic to acidic soils. These may be interpreted as soils with weak buffering system. The C_{ox} value is 4.9%, which is quite a high number considering the siliceous substrate. However, occasionally grazed meadows are enriched with natural organic fertilizers, which affect the higher values of organic carbon. There are three rocky mounds (AFR) with classified silicate anthrosol on a substrate of Permian rocks. They are acidic soils. The value C_{ox} is 5.61%. Relatively high value of organic matter can be justified by form of use, i.e. occasional mowing and grazing of PG. The soil is loamy-sandy.

Mosaic of arable land on permanent grasslands (PG) with loamy-rocky terraces (LT5)

A cultisol on an eluvium substrate of limestones shale is present. It is a carbonatic substrate and also the measured values of pH (H_2O) 7.73 and pH (KCl) 7.26 are corresponding, in the category of alkaline soils with strong buffering system. The C_{ox} value 4.77% is relatively high due to fertilization with natural organic fertilizers. Skeleton content is moderate. The soil is loamy-sandy, with medium to lower accumulative capability. On the loamy terraces a soil subtype – modal cultisols – was classified on a substrate of deluvial-colluvial-loamy rocky sediments of shale. The value of pH (H_2O) is 7.74 and pH (KCl) is 7.18, thus the soil is alkaline with moderately strong to high buffering system. The C_{ox} value is between 3.11% and 3.8% and correlates with the use of the locality as a slope of loamy terrace that is not being mowed (AFR). The skeleton content is generally high. The soil is loamy-sandy.

Mosaic of arable land and permanent grasslands (PG) with loamy-rocky mounds (LT6)

In the evaluated locality occurs cultisolic rendzina on a substrate of deluvium from carbonates. The measured value of pH (H_2O) is 7.47 and of pH (KCl) is 7.08, indicating neutral to slightly alkaline soils with strong buffering system. The C_{ox} value is 4.5%, a relatively high value associated with the presence of carbonates in the soil profile. Occasionally is in the locality present carbonate ranker on carbonate deluviums. The soil reaction is neutral to slightly alkaline due to the carbonate substrate. On the rocky and loamy mounds (AFR) carbonate anthrosol was classified with alkaline soil reaction. The organic matter content is also relatively high (C_{ox} 5.47). The soil is loamy to loamy-sandy.

Extensively used meadows with loamy-rocky terraces (LT7)

On the extensively mowed meadows was classified cultisolic rendzina on limestone deluviums. The value of pH (H_2O) is 7.52 and pH (KCl) value is 7.21, indicating alkaline soils with strong buffering system. The C_{ox} value is 5.89%, a relatively high value resulting from the presence of carbonates in the soil and management, what can be interpreted as soils with medium to high productivity function. On the terraces was diagnosed carbonate cultisol with alkaline soil reaction and relatively high organic matter content, indicated by the C_{ox} value 5.6%.

Quantification of the impact of selected ecological factors on the environmental functions

Selection of input indicators and method of their quantification

We chose multivariable statistical methods to evaluate the diversity of geological substrate, soil subtypes and way of use.

To detect and quantify the highest variability of obtained parameters we used indirect linear gradient analysis performed using CANOCO software. To create the input data table, we used the data from laboratory set soil parameters, results of field landscape research and soil-substrate conditions while keeping the condition of using quantitative and semi-quantitative data type. Tables 1 and 2 include input data table and table with measured values and data.

Interpretation of the results

Impact of ecological factors on buffering functions

Significant bonds between a variable 'geological substrate' and variables 'soil environment pH' were confirmed, namely $R = 0.617$, $P < 0.05$ to the variable pH (H_2O) and $R = 0.634$, $P < 0.05$ to the variable pH (KCl). Negative correlation bonds were shown by the variable 'IV. Grain size category' (content of sandy fraction in %) $R = -0.542$, $P < 0.05$ in a relation to the variables 'pH (H_2O)' and ($R = 0.514$, $P < 0.05$) in relation to the variable 'pH (KCl)'. The size of soil buffering capacity is affected by grain size conditions, soil organic matter content and significantly by the geological bedrock chemistry. On carbonate rocks – dolomites and limestones – with mineral-rich representation of base cations with positive granularity, developed soil subtypes with high buffering system resistant to acidification. On the contrary, low pH values of the soil environment conditioned the occurrence of mineral poor rocks with higher representation of sand fraction, like light-grey conglomerates, colourful sandstones and siltstones.

Impact of ecological factors on production functions

Between the variable 'soil subtype' and the variable 'organic matter content C_{ox}' was observed a positive correlation ($R = 0.555$, $P < 0.05$). The main soil-forming process of dominantly occurring soil subtypes in the evaluated area is accumulation of organic substances, which is determined by the high content of base cations from mineral-rich rock substrates as well as favourable grain size conditions. The foregoing implicates that main factors affecting production functions are mineral-rich rocks, occurrence of base cations and presence of favourable granularity fraction ratios, determining the soil subtype. These facts are also confirmed by similar studies about quantification of links between some abiotic parameters and way of

T a b l e 1. Input data table.

Number of the localities	Sampling sites- Land use	pH/H_2O (-)	pH/KCl (-)	Cox (%)	Soil separate [%]					Soil subtype	Geology
					Physic. clay	I. cat	II. cat	III. cat	IV. cat		
					< 0.002 mm	< 0.01 mm	< 0.01–0.05 mm	0.05–0.1 mm	0.1–2 mm		
1	1-FAR--Z-K	6.02	5.22	3.26	0.81	16.67	41.98	13.31	28.04	1-Skeletic Leptosols	1-conglomerates, sandstones, shales
2	4-EP	5.95	5.02	4.71	1.12	19.97	34.85	13.09	32.09	2-Ari-anthropic regosols	1-conglomerates, sandstones, shales
3	1-FAR--Z-K	7.47	7.07	5.26	0.43	24.27	48.46	15.36	11.91	1-Skeletic leptosols	2-delúvium, weathered clayey and marly shale, chert limestone and Ramsau dolomite
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
21	5-EL	7.52	7.21	5.89	0.25	11.45	44.26	21.59	22.70	6-Rendzic leptosols	5-Ramsau dolomite

T a b l e 2. Table with measured values and data.

Number of the localities	Sampling sites-	pH/H_2O	pH/KCl	Cox (%)	Physic. clay	I. cat %	II. cat %	III. cat %	IV. cat %	Soil sub-type	Geology
	Land use	(-)	(-)		< 0.002 mm	< 0.01 mm	< 0.01–0.05 mm	0.05–0.1 mm	0.1–2 mm		
	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}	X_{110}	X_{111}
X_{11}	1	6.02	5.22	3.26	0.81	16.67	4.98	13.31	28.04	1	1
X_{21}	4	5.95	5.02	4.71	1.12	19.97	34.85	13.09	32.09	2	1
X_{31}	1	7.47	7.07	5.26	0.43	24.27	48.46	15.36	11.91	1	2
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
X_{211}	5	7.52	7.21	5.89	0.25	11.45	44.26	21.59	2.70	6	5

FAR-Z-K – forms of anthropogenic relief (FAR) -loamy-rocky terraces, pH/H_2O – active soil reaction, pH/KCl – exchange soil reaction, C_{ox} – content of organic carbon, EL – extensively used meadows, EP – extensively used pastures, I. cat. – content of colloidal in fraction in %, II. cat.- content of dust fraction in %, III. cat. – content sandy-dust fraction in %, IV.cat. – content of sandy fraction in %.

T a b l e 3. Table of Pearson correlation coefficients.

	land use	*pH(H2O)*	*pH(KCl)*	*Cox(%)*	*Phys.clay*	*I.cat.*	*II.cat.*	*III.cat.*	*IV.cat*	*soil type*	*geology*
land use	1	0.029151	0.025266	-0.16919	0.365474	0.407263	-0.0085	-0.1698	-0.28259	0.283127	-0.0477
pH(H2O)	0.029151	1	0.978071	0.353243	0.360338	0.272389	0.413531	0.055282	-0.54284	0.274252	0.617334
pH(KCl)	0.025266	0.978071	1	0.382174	0.315178	0.198483	0.43905	0.100921	-0.51418	0.247651	0.634385
Cox(%)	-0.16919	0.353243	0.382174	1	-0.07402	-0.40026	-0.02299	0.121217	0.319398	0.555588	0.143844
Phys.clay	0.365474	0.360338	0.315178	-0.07402	1	0.837447	-0.1702	-0.59231	-0.36853	0.18011	0.278278
I.cat.	0.407263	0.272389	0.198483	-0.40026	0.837447	1	-0.04704	-0.67905	-0.55593	-0.12385	0.178264
II.cat.	-0.0085	0.413531	0.43905	-0.02299	-0.1702	-0.04704	1	0.269199	-0.74023	0.03115	0.338717
III.cat.	-0.1698	0.055282	0.100921	0.121217	-0.59231	-0.67905	0.269199	1	-0.0269	0.222309	0.088367
IV.cat	-0.28259	-0.54284	-0.51418	0.319398	-0.36853	-0.55593	-0.74023	-0.0269	1	-0.01147	-0.42413
soil type	0.283127	0.274252	0.247651	0.555588	0.18011	-0.12385	0.03115	0.222309	-0.01147	1	0.184143
geology	-0.0477	0.617334	0.634385	0.143844	0.278278	0.178264	0.338717	0.088367	-0.42413	0.184143	1

Identification of significance of correlation links

Significant (primary) correlation links between variables are those values of Pearson correlation coefficients which fall in the **interval 0.6–1.0.**

Secondary correlation links are those values of Pearson correlation coefficients which fall in the **interval 0.3–0.59.**

Correlation links at the border of significance are those values of Pearson correlation coefficients which fall in the **interval 0.29–0.0** (Krnáčová, Krnáč, 1996).

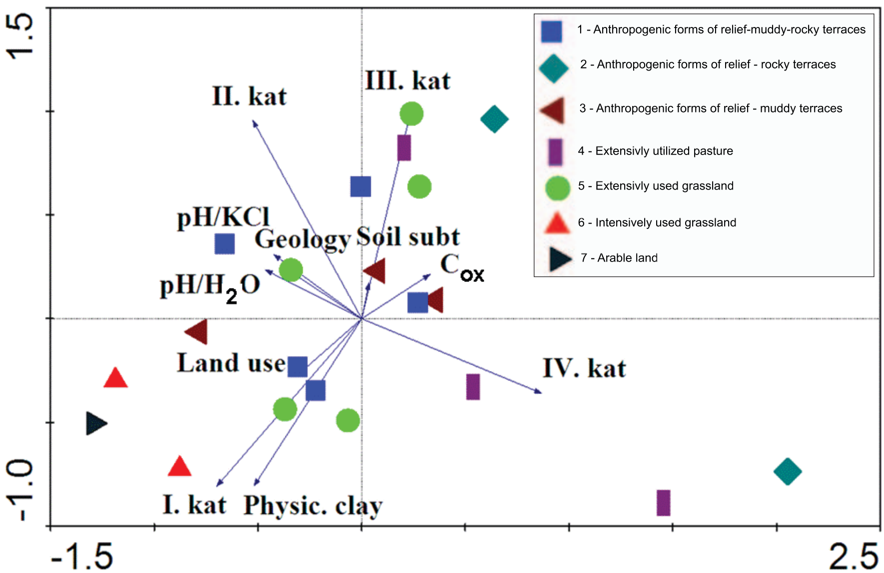

Fig. 4. Ordination graph characterizing bonds of the main components in relation to variables according to PCA.

land use (Krnáčová, Krnáč, 1996, 1999). Due to its low variability – permanent grasslands are dominant – the impact of the way of land use and management was not confirmed in our analyses.

Impact of ecological factors on retention (accumulation) functions

The variable 'IV. Grain size category' (sandy fraction content in %) is in negative correlation with I. (clay particles content in %) and 'II. Grain size category' (dust sandy fraction content v %) ($R = -0.555$, $P < 0.05$ $R = -0.740$, $P < 0.05$). Retention (accumulation) soil function has a significantly physical nature in relation to soil water retention, i.e. it is a function of soil granular fractions ratio. Granular composition of soil primarily affects physical, hydro-physical and chemical properties of soils. Higher proportion of sandy fraction content significantly lowers retention function of soils. Due to its small active surface, sand has low sorption capacity and overall negative effect on hydro-physical soil properties. On the contrary, soils with higher clay particles content (loamy-clayey, clayey-loamy) have very positive effect in physical, hydro-physical and chemical properties of soils.
The ordination graph (Fig. 4) characterizing links between the main components (factors) and the analysed variables is confirmed by the foregoing facts.

Conclusion

Based on the research of selected representative landscape features of traditional agrarian landscape, we can say that the most favourable production and buffering soil functions have been preserved in rendzinas on carbonate substrates of extensively used meadows. Similarly, this type of soils used as extensive meadows have also maintained the most favourable retention functions according to the proportion of granularity of fractions. This is confirmed by the laboratory stated values of C_{ox} in the Ap horizont (7.67–6.62%), as well as the pH value of soil environment (pH/KCl 7.26–7.21, pH/H_2O 7.69–7.68). Relatively lower values of soil organic matter C_{ox} (2.51–2.53%) as well as the pH value of soil environment (pH/KCl 4.81–5.21) (pH/H_2O 5.21–6.19) indicated less favourable production functions of cultisoils of big fields and very low values of buffering and retention functions of soils, set for lithosoil of extensively used pastures on siliceous substrates.

Multivariate analysis of the main components of PCA confirmed the assumption that the size of the buffering capacity of soils is significantly influenced by chemistry of the geological bedrock. Production functions of soils greatly determine the soil subtype, which is confirmed by a significant correlation between the factor (soil subtype) and the variable (C_{ox} – organic matter content). PCA analysis further confirmed that hydro-physical properties of soils and hence also value of retention function of soils is primarily (significantly) determined by a proportional representation of granularity fractions.

Soil is increasingly becoming an endangered natural resource, knowledge of which is vital for sustainable development of human society. Research of traditional agrarian landscape of Liptovská Teplička in the foothill region is a good example of creating the preconditions of sustainable state of high landscape and biological diversity as well as the production state of agriculture in expanding its non-productive functions.

Acknowledgements

This contribution was developed in the course of the project SK0088 'Výskum a zachovanie biodiverzity v historických štruktúrach poľnohospodárskej krajiny Slovenska' (Research and Conservation of Biodiversity in Historical Structures of Slovak Agricultural Landscape) supported by the EEA Financial Mechanism, Norwegian Financial Mechanism and from the Slovak State Budget and with the support by the Slovak Research and Development Agency under the contract No. APVV-0669-11.

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