Changes of forest abiotic environment in the Western Carpathians assessed using phytoindication

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ABSTRACT: To avoid ecosystem degradation, forestry planning needs to be based on current information about the state of forest environment. Phytoindication is an inexpensive tool that allows tracking the environmental change at fine spatial scales. The present study uses this approach to assess changes within abiotic conditions of forests in the area of the Moravian-Silesian Beskids Mts. (Czech Republic). Phytosociological relevés collected in 2013 at 118 permanent plots were compared with records from the 1960s and 1970s. The changes were expressed using average Ellenberg's Indicator Values and units of the Czech Forest Typological System. Persisting soil acidification was detected, and linked to industrial deposition and planting of Norway spruce beyond its natural range. Conversion towards a higher share of broadleaved species was suggested to support soil recovery.

Keywords: Beskids Mts.; Ellenberg's indicator values; forest typology; Norway spruce; soil acidification

The Carpathian Mountains belong to the most important European biocentres, being a provider of ecosystem services on which many human communities depend (Gurung et al. 2009). Among the services delivered by mountain forests, there is the supply of wood and other forest products. By careful planning, modern forestry strives to optimize these outputs, at the same time avoiding the ecosystem degradation. Management plans have to consider the parameters of the abiotic environment of each forest stand (Vacek, Balcar 2004).

In the forestry practice of the Czech Republic, these characteristics are expressed using units of the Czech Forest Typological System. Among the units there are forest vegetation zones which take their names from edificator species and describe the variability of local climate with changing altitude and exposition, and edaphic categories which describe the soil trophic and hydric regime and are denoted using single-letter mnemonics (Viewegh et al. 2003).

The parameters of the forest abiotic environment covered by these units are referred to as "permanent environmental conditions" (Viewegh et al. 2003). It can be argued, however, that these characteristics are not only variable but given the current scale of anthropogenic disturbance (Steffen et al. 2011) while rate of their change has dramatically accelerated. The increasing speed of environmental change calls for an introduction of adaptive management strategies into forestry practice. In order to be successful, this approach needs to be based on current data (Lindner et al. 2010).

The goal of the present study is to analyze recent changes within the forest abiotic environment of a Western Carpathian mountain range using phytoindication. The trends of change are described by referring to average Ellenberg's Indicator Values (AIVs) and the units of the Czech Forest Typological System. Recommendations for the local forest management are given.

According to Hédl (2004), three major trends of anthropogenic change may currently be taking place within the abiotic environment of forest ecosystems of Central Europe: (1) soil acidification caused by the deposition of air pollutants; (2) eu-

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trophication due to the pollution and the overpopulation of herbivores; (3) shifts related to the global climate change.

With the exception of minor fragments, the Carpathian Mts. lie within the boundaries of the former Communist Bloc, where the economy was based on heavy industry, and environmental regulations were sloppy. For decades, the ecosystems were exposed to high air pollution levels, resulting in the deposition of sulphur and nitrogen compounds, which have been contributing to the decline of forest health. The affected stands include Norway spruce (*Picea abies* [L.] Karsten) monocultures, whose widespread presence has been the legacy of the 19th century forestry policy (Main-Knorn et al. 2009).

After the Fall of Communism, the industrial emissions have been reduced and many forest stands have been undergoing conversion toward a higher share of broadleaved species (Main-Knorn et al. 2009). While in theory both trends create an opportunity for the edaphic environment to recover, evidence of such a recovery has been scarce so far: recent measurements of the forest environment quality in the Czech (Novotný et al. 2008), Slovak (Sitková et al. 2010) and Romanian (Bytnerowicz et al. 2005; Badea et al. 2012) parts of the Carpathian Mountains give a picture of high soil acidification levels that have been persisting despite a substantial reduction of pollutant concentrations in the atmosphere. The affected ecosystems include not only those located in the proximity of pollution sources: Šebesta et al. (2011) studied changes that had occurred since the 1930s in the soil environment of a primeval forest ecosystem in the Ukrainian Carpathians, close to the Romanian border. Despite the large distance dividing their study area from industrial centres, the evidence of acidification was present in the samples. The results agree with the findings of Oulehle et al. (2010) pertaining to the same mountain range. Interestingly, the latter authors did not observe substantial soil acidification in another part of the Ukrainian Carpathians, next to the Slovak border. This discrepancy was explained as the result of differing parent bedrocks at both localities. On the other hand, the analysis of the soil drainage water collected in the area less affected by acidification revealed intensive leaching of nitrogen, suggesting a high level of eutrophication (Oulehle et al. 2010). Another notable exception is the Polish study on the forest health status in national parks. On several permanent plots, located mostly in the Carpathians, the authors surveyed Ca to Al ratios of soil. The obtained values did not suggest high acidification levels (Staszewski et al. 2012).

The data on climatic changes are available in the form of meteorological reports and the outputs of climatological models (e.g. Nogués-Bravo et al. 2007; Hlásny et al. 2011). According to the predictions, by the end of the 21st century, lower Carpathian ranges are going to be subjected to drought events, whereas at higher elevations temperature increases are likely to occur – potentially boosting forest productivity (Lindner et al. 2010; Hlásny et al. 2011). Unfortunately, due to the coarse spatial scales involved in such assessments (Nogués-Bravo et al. 2007), the possibilities of their application in adaptive forest management are limited. This is especially true of mountain ranges, which are characterized by rich relief, resulting in a high variation of habitat types (Nepal, Chipeniuk 2005).

A particular approach to environmental monitoring that does not rely on specialist equipment and expensive analyses (Diekmann 2003) and which makes it possible to obtain data with high spatial resolution (Balkovič et al. 2010) is to use phytoindication. Under this approach repeated sampling of phytosociological permanent plots is performed, and observed shifts in the vegetation composition are interpreted in terms of environmental change by referring to the changes of average Ellenberg's Indicator Values (AIVs).

The reports from phytosociological studies carried out in the Czech (Šamonil, Vrška 2007) and Polish (Durak 2010, 2011) Carpathians mention a decrease of AIV R, indicating a trend towards the lower soil pH or calcium concentration (Diekmann 2003). An opposite direction of change was detected at Norway spruce-dominated stands in the Ukrainian part of the mountains; interestingly, the result was not consistent with the results of soil analyses (Šebesta et al. 2011). According to the authors, this discrepancy could be explained by high resistance of the phytocoenoses to habitat disturbances or by colonization of low tree layers by broadleaved woody species. The same study reported increasing AIV N, what can be interpreted as soil enrichment in nitrogen, or more intensive biomass production (Diekmann 2003). The authors linked this observation to atmospheric nitrogen deposition and shifting forest developmental phases (Šebesta et al. 2011). A different result was obtained by Durak (2011) in the Polish Carpathians. The AIV N decrease was interpreted as the consequence of silvicultural operations. Some researchers (Šamonil, Vrška 2007; Durak 2010; Šebesta et al. 2011) reported changes of AIV L, but as pointed out by Diekmann (2003), the reliability of this light-related parameter is low, as its values do not correlate well with measured light intensity over short gradients.

Owing to the fact that the definition of the units of the Czech Forest Typological System is closely related to the distribution of potential vegetation (Viewegh et al. 2003), they can be used in a similar way like AIVs to monitor changes within the forest abiotic environment. Viewegh (1999) used this approach to interpret vegetation shifts in the Moravian-Silesian Beskids Mts. (Western Carpathians). Between 1984 and 1986, the author resampled 390 permanent plots and compared the relevés with earlier records, probably collected in the 1930s, using an unconstrained ordination. By referring to the typological classification of the plots, he concluded that the abiotic characteristics of the ecosystems had been changing towards conditions typical of sparse high-mountain stands.

The phenomena that are related to the global climate change and which can be monitored using phytoindication methods include the shifts of mountain vegetation zones towards peak elevations. Under the assumption that the ranges of many plant species are constrained primarily by climatic factors, with the climate change progression it is reasonable to expect widespread migrations of populations following their shifting niches (Bertin 2008). To my knowledge, no such response of phytocoenoses to the changing environment has been observed in the Carpathians so far; there are, however, research reports suggesting migrations of this kind have been taking place in some other mountain ranges (e.g. Kelly, Goulden 2008; Bai et al. 2011; Feeley et al. 2011). In the European context, notable is the study by Lenoir et al. (2008), who compared vegetation records that had been collected over two time periods in six mountain ranges of Western Europe. The authors concentrated on changes within the species altitudinal optima and reported that two-thirds of the taxa had changed their distribution ranges toward higher elevations, whereas the remaining fraction showed the opposite trend of migration.

MATERIAL AND METHODS

The research was conducted at the top elevations of the Moravian-Silesian Beskids Mts., which belong to the Western Carpathians and are located in the eastern part of the Czech Republic. This mountain range is characterized by a high share of forest cover, reaching 75% of the total land area, and plant species richness exceeding one thousand taxa. Notable are high precipitation sums, which amount to 900–1,377 mm per annum. Annual mean temperatures are in the 2.3–7.8°C range. The dominating soil type is Cambisol, which has been formed on the flysch bedrock. The potential vegetation of the area consists mainly of European beech (*Fagus sylvatica* L.) forests, but the species has been largely replaced by Norway spruce, planted beyond its natural range and currently prevailing in the tree composition (Vacek 2003).

Between July and September 2013, 198 phytosociological relevés (hereafter, 2013 relevés) were collected at permanent plots maintained by the Forest Management Institute in Brandýs nad Labem, Czech Republic. The plots selected for the study had 400–500 m² surface area and were located in the fir-beech (500–1,000 m a.s.l. altitude range), spruce-beech (555–1,120 m a.s.l.) and beech-spruce (830–1,220 m a.s.l.) forest vegetation zones.

The plots were relocated using a GPS device. At each locality, the abundance-dominance of vascular plant species and the *Sphagnum* mosses were registered on the 11-point Zlatník scale. To reduce the influence of relocation errors, the relevés collected in heterogeneous stands were excluded from further analysis. Due to their insufficient amount, also the data from nature reserves and other small-scale specially protected areas were discarded, resulting in the final number of 118 relevés (one relevé per one permanent plot).

Table 1. Typological classification of permanent plots, absolute frequencies given (n = 118)

Forest vegetation zone	Edaphic category														
	J	D	U	B	A	F	H	S	K	N	Z	Y	V	G	O	T
Beech-spruce	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	1
Spruce-beech	0	0	0	0	0	6	0	3	0	2	0	0	1	2	4	0
Fir-beech	4	3	2	12	10	24	4	21	9	2	0	1	2	0	2	0

J – eutrophic talus, D – eutrophic colluvial, U – ravines and gulleys, B – typical mesotrophic, A – eutrophic stony-colluvial, F – mesotrophic stony, H – mesotrophic loamy, S – transitional meso- to oligotrophic, K – typical oligotrophic, N – oligotrophic stony, Z – scrub, Y – extreme skeletal, V – eutrophic moist to wet, G – mesotrophic wet, O – mesotrophic gleyed, T – oligotrophic gleyed

The plots show an unbalanced representation of typological units (Table 1), reflecting the variable frequency of forest site type occurrence in the mountain range. Among the edaphic categories, the most common are: the category F, indicating mesotrophic forests growing on stony slopes, and the transitional meso- to oligotrophic category S (Viewegh et al. 2003). Lower is the representation of typical meso- and oligotrophic forests classified into the categories B and K, respectively, as well as eutrophic stands bound to areas of colluvial nutrient accumulation (category A). Scarce are the data from forests growing on wet, gleyed soils (categories V, G, O, T) or in extreme environmental conditions (categories Z and Y). For a more comprehensive description of edaphic categories the reader is referred to Viewegh et al. (2003). As far as the forest vegetation zones are concerned, the relevés from the fir-beech zone form the bulk of the dataset, whereas the records from higher elevations are limited in number.

The data collected at the plots were subjected to numerical analysis using the R environment (R Foundation for Statistical Computing, Vienna, Austria). In order to describe the changes that had taken place in the vegetation patterns during the previous decades, the 2013 dataset was merged with 78 records from the 1960s and 78 records from the 1970s (hereafter, historical relevés; Fig. 1) collected at the same permanent plots. The 1960s can be characterized as the decade of a sharp increase of industrial emissions (Oulehle et al. 2010), but at that time the pollution impact on forest health in the Moravian-Silesian Beskids area was just beginning to show. The damage culminated at the end of the 1970s (Vacek 2003).

The majority of the relevés in the merged dataset represent stands where Norway spruce was either the dominant or the only tree species at the time of the sampling (Table 2). They are followed by forests characterized by a high share of European beech. Other recorded tree species include: sycamore maple (*Acer pseudoplatanus* L.), silver fir (*Abies alba* Mill.), Scots pine (*Pinus sylvestris* L.), and European larch (*Larix decidua* Mill.). Some of the permanent plots with high canopy closure at the time of their establishment occurred to be only sparsely vegetated with trees during their resampling at a later time.

Considering the limited bioindicative value of tree species found in production forests, the subsequent parts of the study concentrated on the moss, herb and low shrub layers. The Zlatník abundance-dominance values were converted into cover percentages and the species that had posed identification problems were amalgamated. Because the relevés had been collected by various persons, and because the taxa in the dataset occurred with variable frequency, a Wisconsin double standardization was applied to the values.

The dimensionality of the dataset was then reduced to four dimensions using the Nonmetric Multidimensional Scaling (NMDS) method. The ordination was based on the Bray-Curtis distance matrix and involved 100 random starting configurations. A two-dimensional ordination was also tried, but it had to be discarded due to high stress value. The ordination plots obtained from the more complex model were partitioned into sub-plots representing units of the Czech Forest Typological System. The relevés were assigned to the ordination sub-plots according to the typological classification of permanent plots provided by the Forest Management Institute.

In the next step, six unweighted average Ellenberg's Indicator Values (AIV) were calculated for each relevé and used as input data for general additive models (GAM). The values fitted by the models were represented graphically in the NMDS ordination space using isolines. Additionally, a series of mixed-effect regression models, with each AIV as the dependent variable, time as the fixed independent variable and permanent plot as the random intercept variable, was fitted. As some relevés were missing one or more AIV values, this calculation was based on a reduced dataset representing 101 plots. The model performance was diagnosed by analysing the distribution of residuals, and its output was used to estimate 95% confidence intervals of AIV changes over the period between the date of the oldest relevé (i.e. the year 1961) and the summer 2013. The linear modelling was repeated using weighted instead of unweighted AIVs as dependent variables.

196	1111444444444444444444444444444444444444444444444444444444444444
196	88888888888888
197	222222222222233333333333333333333333333333333333333444444444444444
197	888888888888

Fig. 1. Stem and leaf plot of the years when the historical relevés were collected

Table 2. Tree compositions of permanent plots in different periods of vegetation sampling, absolute frequencies given

Tree composition		Sampling period		
		1961–1968 (n = 78)	1972–1978 (n = 78)	2013 (n = 118)
Single-species, consisting of	Norway spruce	29	27	34
	European beech	4	6	6
	Sycamore maple	2	2	0
Mixed, dominated by	Norway spruce	25	22	45
	European beech	8	13	21
	Sycamore maple	4	3	2
	Silver fir	5	2	0
	Scots pine	1	0	1
With canopy closure not exceeding 10%		0	3	9

The directions of change within the vegetation composition of the permanent plots were then assessed by comparing the locations of the 2013 relevés in the ordination space in respect to the locations of the historical relevés. The observed shifts were translated into changes of the forest abiotic environment using the results of AIV modelling and the information about the typological classification of the plots. As interpretable patterns of change were visible only in the first two dimensions

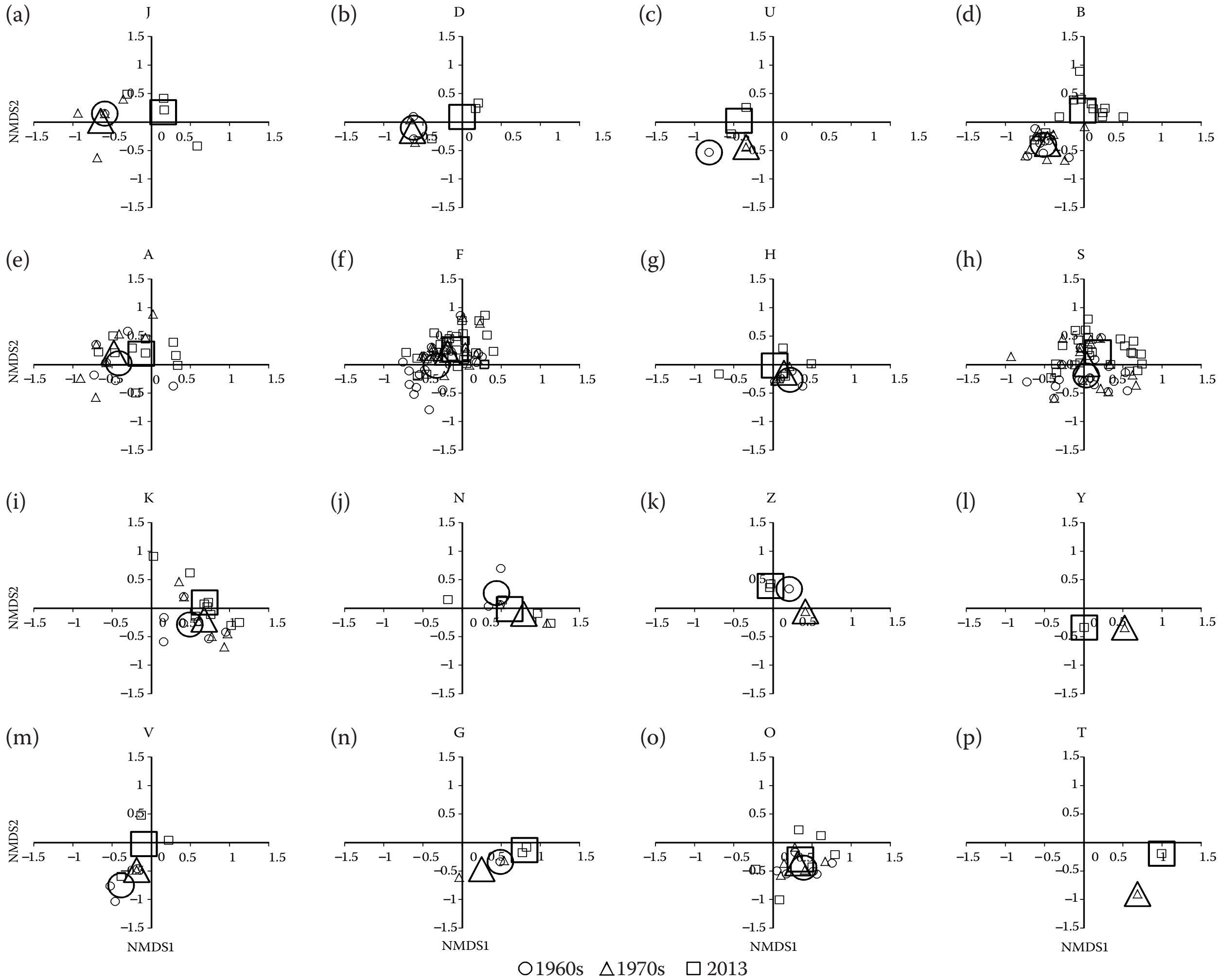

Fig. 2. The first two-dimensions of the NMDS ordination space with observations partitioned into edaphic categories and differentiated according to the sampling period; large symbols represent weight centres of each group

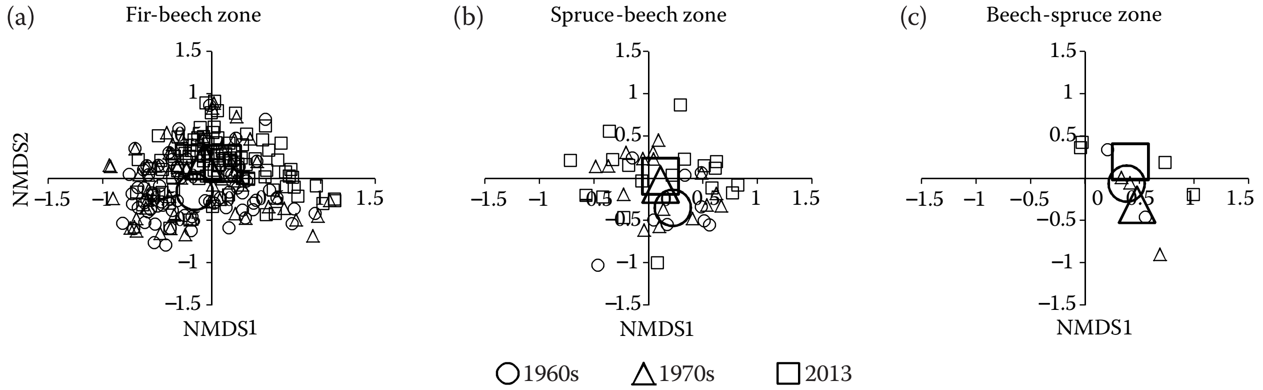

Fig. 3. The first two dimensions of the NMDS ordination space with observations partitioned forest vegetation zones and differentiated according to the sampling period (a–c); large symbols represent weight centres of each group

of the ordination, the remaining two are not presented in this paper.

RESULTS

The obtained NMDS ordination is characterized by the stress value close to 0.16, indicating a good fit and an improvement over the two-dimensional ordination (stress value of 0.26). After partitioning into edaphic categories (Fig. 2), several clusters of historical relevés (marked with circles and triangles on the plots) can be distinguished: the left-hand side of the ordination space is occupied by observations originating from eutrophic sites (category J) and the sites belonging to the mesotrophic category B. In the central part, relevés collected in meso- to oligotrophic (S) habitats predominate. These two clusters share the space with the categories A and F, which are assigned to forests growing on slopes. The right-hand side groups relevés from oligotrophic sites (category K) and mesotrophic sites with gleyed soils (category O). The remaining edaphic categories covered by the study are poorly represented.

Partitioning according to the forest vegetation zones (Fig. 3) reveals no apparent altitudinal gradi-

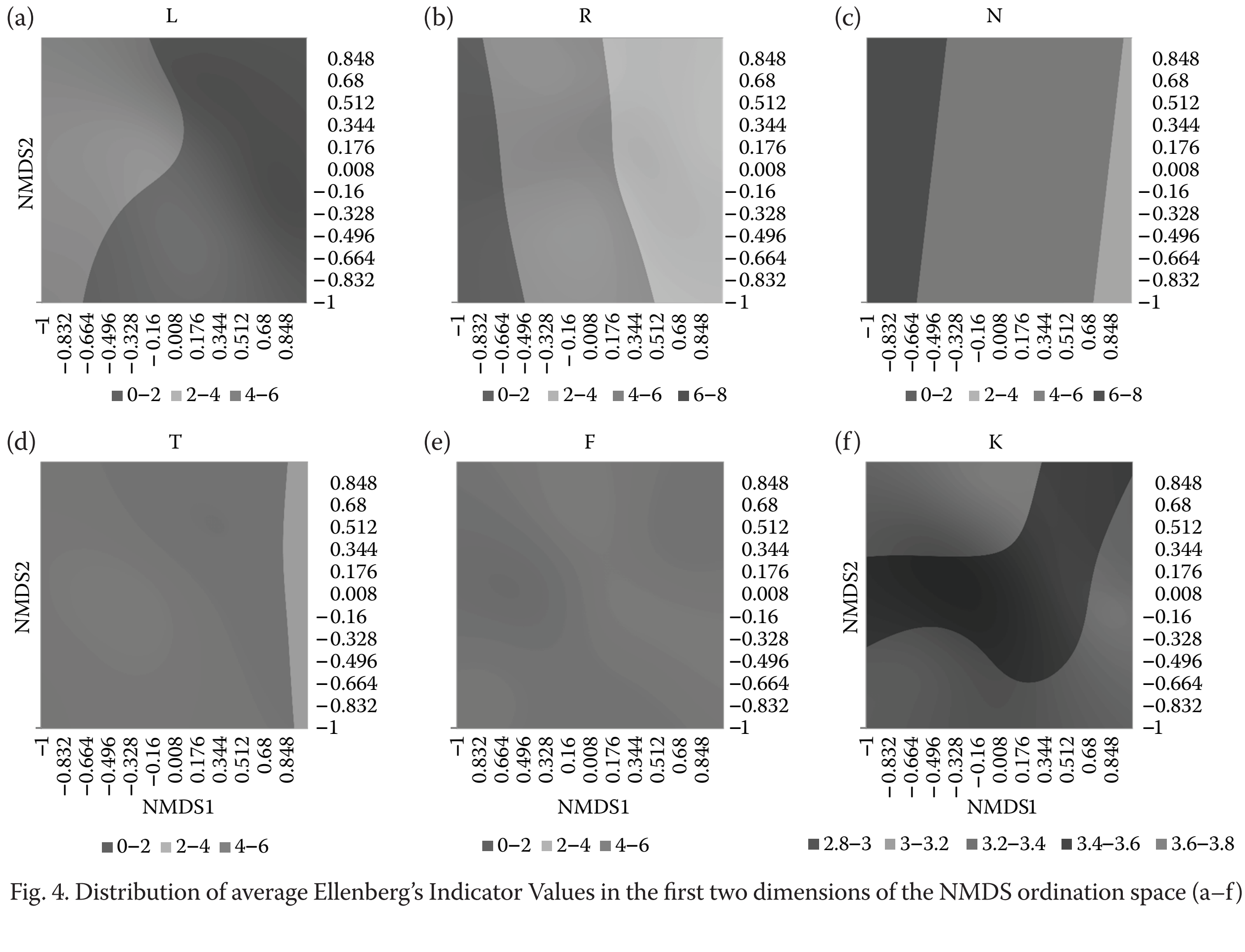

Fig. 4. Distribution of average Ellenberg's Indicator Values in the first two dimensions of the NMDS ordination space (a–f)

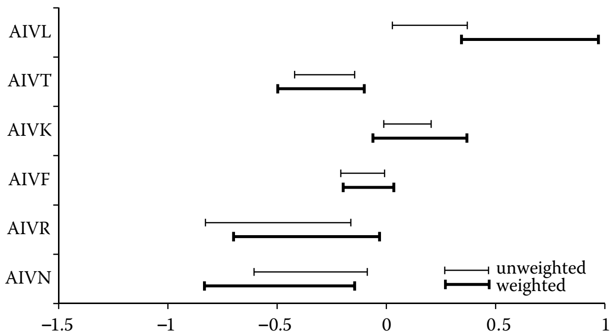

Fig. 5. Ninety-five percent confidence intervals of the change within unweighted and weighted average Ellenberg's Indicator Values over the 1961–2013 period

ent. Although the historical relevés collected in the lowest of the studied tiers (i.e. the fir-beech zone) tend to occur on the left side of the ordination space, whereas those from near-peak elevations (the beech-spruce zone) seem to be found on the opposite side, the latter are underrepresented and no reliable judgement can be made.

The distribution of the average Ellenberg's Indicator Values (Fig. 4) logically matches the distribution of the typological units: high AIV L values are found on the right-hand side of the ordination space and can be associated with high-mountain stands, whereas the AIV R and N values increase toward the cluster of the nutrient-rich sites. The three remaining AIVs show a weak gradient.

The positions of the historical relevés collected in the 1960s (circles) do not differ much from the relevés originating from the 1970s (triangles). When the positions of the 2013 relevés (marked with squares) are considered, a roughly uniform pattern of change reveals itself: during the studied period, the plant composition of the plots has shifted towards that typical of oligotrophic forests growing on acidic, calcium-poor soils (edaphic category K; low AIV R) and stands that occur at high elevations (high AIV L) or on gleyed soils (edaphic category O). Lower is the share of the species commonly found at nutrient-rich localities (categories J and B; high AIV N).

For four of the six AIVs a significant value of regression slope was obtained regardless of whether unweighted or weighted values were used (Fig. 5). The confidence interval of the weighted AIV L change over the 1961–2013 period (95% CI 0.34 to 0.97 units, 133 df, $P < 0.001$) is wide, but far from zero, whereas the unweighted AIV L (95% CI 0.03–0.37, 133 df, $P = 0.002$) has reverse characteristics. In the remaining dependent variables with both significant slope values (i.e. AIV T, R and N), the confidence intervals do not differ much under the different approaches to AIV calculation. In the course of the model diagnostics, distributions of residuals occurred to be close to normal, but standardized residuals showed correlations with fitted values. For this reason, the true confidence intervals are probably wider than the calculated ones, and the unweighted AIV L, unweighted AIV F and weighted AIV R slope values cannot be trusted to be significant.

DISCUSSION

The increased floristic resemblance of the 2013 relevés to that typical of the forest sites described as oligotrophic and acidic suggests that in the top ranges of the Moravian-Silesian Beskids region the acidification levels of the soils are currently higher than during the post-war industrialization period. This conclusion is further supported by the observed AIV R (unweighted only) and AIV N (both weighted and unweighted) decreases, and is consistent with the results of studies done in some other parts of the Carpathian Mountains (Šamonil, Vrška 2007; Novotný et al. 2008; Durak 2010, 2011; Badea et al. 2012). Various authors provided different explanations of this phenomenon. Given the proximity of large industrial centres – Ostrava, Třinec and Katowice agglomeration – to the research area, it can be assumed that in the case of the Beskids Mts. the observed changes are related to airborne pollutants, whose influence has been persisting despite decreased emission levels. Following the reasoning of Oulehle et al. (2010), the local soils could be expected to have high buffering capacity. However, similarly like in the study done by Durak (2010), the acidification has been taking place in spite of the occurrence of the flysch bedrock in the studied region.

The pollution impact has likely been augmented by the maintenance of Norway spruce plantations on large areas of the mountain range. The acidifying effect of this species is well documented (Augusto et al. 2002). The authors warn against establishing Norway spruce monocultures at the sites of high acidic deposition, where the soil buffering capacity has been exhausted. Resulting stands are sensitive to disturbances and often show signs of health damage (Novotný et al. 2008; Badea et al. 2012).

The emission rates are beyond the control of forest managers, but the soil quality can be improved by changing the forest tree composition. The results of unreplicated measurements of soil properties under first-generation forests in the Beskids region suggest that replacing Norway spruce with broadleaved species can support soil recovery in this mountain range (Novák et al. 2012). A simulation of future soil conditions in the Krušné hory Mts. (the Czech-German border) brought similar conclusions (Oulehle et al. 2007). The conversion of Western Carpathian conifer forests into mixed ones between 1987 and 2005 was documented using remote sensing methods (Main-Knorn et al. 2009), yet Norway spruce is still overrepresented in this region. In the previous decade it made almost 75% of the Moravian-Silesian Beskids forest cover (Vacek 2003). The conversion needs to be continued.

In contrast with soil acidification, changes in the light conditions of Carpathian forests have seldom been reported (Šamonil, Vrška 2007; Durak 2010; Šebesta et al. 2011), and the observations do not agree with each other. In the present study, an increased share of understorey species with high light Ellenberg's Indicator Values was detected, but only the change of weighted AIV L was judged to be statistically significant. The evidence obtained in the typological part of the analysis is also weak due to the insufficient number of observations from stands growing in extreme conditions. This kind of forests tends to have a status of small-scale specially protected areas and could not be covered by the present study. A shift of relevés in the ordination space toward the area occupied by observations from such stands was reported by Viewegh (1999), who had explored vegetation changes of the same mountain range. Unfortunately, his analysis was based on a DCA ordination and the mentioned pattern occurred along the second axis, which tends to be deformed under this method.

Due to the small number of relevés collected at high-mountain stands the hypothesis about climate change-induced upslope shifts of plant populations could not be confirmed. On the contrary, the direction of the change of AIV T suggests slight cooling of the forest climate. The influence of the global climate change on the abiotic conditions of the forests in the studied area might have been too small to exceed the influence of other factors in the shaping of vegetation patterns.

The translocation of the 2013 relevés towards the part of the ordination space representing plant communities growing on gleyed soils suggests increasing water availability. Again, the available evidence is weak due to the insufficient number of observations collected in wet forest stands. In the Moravian-Silesian Beskids Mts., habitats of this kind occur mainly in lower vegetation zones (Viewegh 1999), which were omitted by the present study. Were the evidence to be accepted, the result would contrast with the predictions of increasing drought frequencies at the top elevations of the Moravian-Silesian Beskids Mts. near the end of the 21st century (Hlásny et al. 2011).

CONCLUSIONS

In comparison with the period of the post-war industrialization, the current composition of the understorey plants in the top forest vegetation zones of the Moravian-Silesian Beskids Mts. shows an increased proportion of acidophilous and oligotrophic species. This finding suggests persisting acidification of forest soils – probably in the result of past industrial emissions as well as forestry policy promoting Norway spruce monocultures. A reduction of the extent of spruce plantations in favour of stands composed of broadleaved tree species should be considered as a way to support soil recovery.

No vegetation shifts that could be related to the global climate change were found. Some evidence of increasing light intensity and soil humidity is present, but it is weak due to an insufficient amount of data collected in wet and sparsely forested stands. In order to facilitate the monitoring of forest abiotic environment in the future, the establishment of additional permanent plots – located at high elevations, within small-scale specially protected areas and on wet soils – should be considered.

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References

Augusto L., Ranger J., Binkley D., Rothe A. (2002): Impact of several common tree species of European temperate forests on soil fertility. Annals of Forest Science, **59**: 233–253.

Badea O., Bytnerowicz A., Silaghi D., Neagu S., Barbu I., Iacoban C., Iacob C., Guiman G., Preda E., Seceleanu I., Oneata M., Dumitru I., Huber V., Iuncu H., Dinca L., Leca S., Taut I. (2012): Status of the Southern Carpathian forests in the long-term ecological research network. Environmental Monitoring Assessment, ***184***: 7491–7515.

Bai F., Sang W., Axmacher J.C. (2011): Forest vegetation responses to climate and environmental change: A case study from Changbai Mountain, NE China. Forest Ecology and Management, ***262***: 2052–2060.

Balkovič J., Kollár J., Čemanová G., Šimonovič V. (2010): Indicating soil acidity using vegetation relevés in spatially limited areas – case study from the Považský Inovec, Slovakia. Folia Geobotanica, ***45***: 253–277.

Bertin R.I. (2008): Plant phenology and distribution in relation to recent climate change. Journal of the Torrey Botanical Society, ***135***: 126–146.

Bytnerowicz A., Badea O., Popescu F., Musselman R., Tanase M., Barbu L., Frączek W., Gembasu N., Surdu A., Danescu F., Postelnicu D., Cenusa R., Vasile C. (2005): Air pollution, precipitation chemistry and forest health in the Retezat Mountains, Southern Carpathians, Romania. Environmental Pollution, ***137***: 546–567.

Diekmann M. (2003): Species indicator values as an important tool in applied plant ecology - a review. Basic and Applied Ecology, ***4***: 493–506.

Durak T. (2010): Long-term trends in vegetation changes of managed versus unmanaged Eastern Carpathian beech forests. Forest Ecology and Management, ***260***: 1333–1344.

Durak T. (2011): Zmiany roślinności żyznej buczyny karpackiej z miesiącznicą trwałą *Lunaria rediviva* na podstawie analizy warstwy zielnej (Góry Słonne, Karpaty Wschodnie). [Changes in vegetation of fertile Carpathian beech forests with perennial honesty *Lunaria rediviva* based on analysis of the herb layer (Słonne Mountains, Eastern Carpathians).] Sylwan, ***155***: 120–128.

Feeley K.J., Silman M.R., Bush M.B., Farfan W., Cabrera K.G., Malhi Y., Meir P., Salinas R.N., Quisiyupanqui M.N.R., Saatchi S. (2011): Upslope migration of Andean trees. Journal of Biogeography, ***38***: 783–791.

Gurung A.B., Bokwa A., Chełmicki W., Elbakidze M., Hirschmugl M., Hostert P., Ibisch P., Kozak J., Kuemmerle T., Matei E., Ostapowicz K., Pociask-Karteczka J., Schmidt L., van den Linden S., Zebisch M. (2009): Global Change Research in the Carpathian Mountain Region. Mountain Research and Development, ***29***: 282–288.

Hédl R. (2004): Vegetation of beech forests in the Rychlebské Mountains, Czech Republic, re-inspected after 60 years with assessment of environmental changes. Plant Ecology, ***170***: 243–265.

Hlásny T., Holuša J., Štěpánek P., Turčáni M., Polčák N. (2011): Expected impacts of climate change on forests: Czech Republic as a case study. Journal of Forest Science, ***57***: 422–431.

Kelly A.E., Goulden M.L. (2008): Rapid shifts in plant distribution with recent climate change. Proceedings of the National Academy of Sciences of the United States of America, ***105***: 11823–11826.

Lenoir J., Gégout J.C., Marquet P.A., de Ruffray P., Brisse H. (2008): A significant upward shift in plant species optimum elevation during the 20th century. Science, ***320***: 1768–1771.

Lindner M., Maroschek M., Netherer S., Kremer A., Barbati A., Garcia-Gonzalo J., Seidl J., Delzon S., Piermaria C., Kolström M., Lexer M.J., Marchetti M. (2010): Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. Forest Ecology and Management, ***259***: 698–709.

Main-Knorn M., Hostert P., Kozak J., Kuemmerle T. (2009): How pollution legacies and land use histories shape post-communist forest cover trends in the Western Carpathians. Forest Ecology and Management, ***258***: 60–70.

Nepal S.K., Chipeniuk R. (2005): Mountain tourism: toward a conceptual framework. Tourism Geographies, ***7***: 313–333.

Nogués-Bravo D., Araújo M.B., Errea M.P., Martínez-Rica J.P. (2007): Exposure of global mountain systems to global warming during the 21st century. Global Environmental Change, ***17***: 420–428.

Novák J., Slodičák M., Kacálek D., Dušek D. (2012): Deciduous tree species affect nutrient cycling compared to Norway spruce – a possible solution to ameliorate forest soil under declining spruce monocultures. In: Boltižiar M. (ed.): Forum Carpaticum 2012: From Data to Knowledge – from Knowledge to Action. Stará Lesná, 30. May–2. June 2012. Nitra, Institute of Landscape Ecology, Slovak Academy of Sciences: 23–26.

Novotný R., Lachmanová Z., Šrámek V., Vortelová L. (2008): Air pollution load and stand nutrition in the Forest District Jablunkov, part Nýdek. Journal of Forest Science, ***54***: 49–54.

Oulehle F., Hleb R., Houška J., Šamonil P., Hofmeister J., Hruška J. (2010): Anthropogenic acidification effects in primeval forests in the Transcarpathian Mts., western Ukraine. Science of the Total Environment, ***408***: 856–864.

Oulehle F., Hofmeister J., Hruška J. (2007): Modeling of the long-term effect of tree species (Norway spruce and European beech) on soil acidification in the Ore Mountains. Ecological Modelling, ***204***: 359–371.

Šamonil P., Vrška T. (2007): Trends and cyclical changes in natural fir-beech forests at the north-western edge of the Carpathians. Folia Geobotanica, ***42***: 337–361.

Šebesta J., Šamonil P., Lacina J., Oulehle F., Houška J., Buček A. (2011): Acidification of primeval forests in the Ukraine Carpathians: Vegetation and soil changes over six decades. Forest Ecology and Management, ***262***: 1265–1279.

Sitková Z., Pavlenda P., Pavlendová H., Priwitzer T., Hlásny T. (2010): Air pollution load and nutrient status of Norway spruce forest stands in the north-western part of Slovakia. Beskydy, ***3***: 93–102.

Staszewski T., Kubiesa P., Łukasik W. (2012): Response of spruce stands in national parks of southern Poland to air pollution in 1998–2005. European Journal of Forest Research, ***131***: 1163–1173.

Steffen W., Persson Å., Deutsch L., Zalasiewicz J., Williams M., Richardson K., Crumley C., Crutzen P., Folke C., Gordon L., Molina M., Ramanathan V., Rockström J., Scheffer M., Schellnhuber H.J., Svedin U. (2011): The anthropocene: from global change to planetary stewardship. Ambio, ***40***: 739–761.

Vacek S. (ed.) (2003): Horské lesy České republiky. [Mountain Forests of the Czech Republic.] Praha, Ministerstvo zemědělství České republiky: 313.

Vacek S., Balcar V. (2004): Sustainable management of mountain forests in the Czech Republic. Journal of Forest Science, ***50***: 526–532.

Viewegh J. (1999): Změny lesních společenstev Moravskoslezských Beskyd v období mezi lety 1970–1986. [Changes in forest communities in the Moravskoslezské Beskydy Mts., N Moravia, in the period of 1970–1986.] Zprávy České botanické společnosti, ***34***: 103–106.

Viewegh J., Kusbach A., Mikeska M. (2003): Czech forest ecosystem classification. Journal of Forest Science, ***49***: 85–93.

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