Myriapods and Isopods of Spruce and Beech Mountain Forests in the Moravian-Silesian Beskids

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Abstract

In forest management, forest typology is often used in long-term planning. Its basic unit is forest site, which represents a relatively permanent biocoenosis with phytocoenological similarity. Some animal species respond to changes in the ecosystem faster than flora and therefore can be used as bioindicators of ecosystem development and stability.

In the network of 38 localities covering 12 forest site complexes (FSC), occurrence of millipede, centipede and terrestrial isopods was investigated (a method of pitfall traps, 14.851 ex., 42 species). In order to specify the environmental characteristics, data from 30 weather stations were used, detailed pedological research including soil chemistry and phytocoenological research were carried out. Obtained data were processed by non-metric multidimensional scaling (MNDS), principal component analysis (PCA) and canonical correspondence analysis (CCA). Distribution of certain species in relation to different forest site complexes was determined by CCA analysis. Discriminating factors were coverage by herbaceous vegetation and contents of Ca and Mg in soil. All three studied groups of species, i.e. millipedes, centipedes and terrestrial isopods, were evaluated as significant for bioindication within the forest ecosystems. Centipedes and millipedes enabled us to associate each FSC with a specific species. Terrestrial isopods indicated well the localities with high groundwater level and the process of peat formation.

Key words: centipede, millipede, indicator of forest site complex, mountain, Norway spruce, beech.

Introduction

Forest typology (Zlatník 1956, Plíva 1971) is based on recognition of autochthonous and changed groups of biocoenoses and their development stages including their environment, biocoenoses developmentally close to each other according to their phytocoenological similarity. The basis is knowledge of the undergrowth synusia (plant component) complemented with ecological (habitat) characteristics (Buček and Lacina 1999). Animals react sensitively to changes in development of ecologic factors in the ecosystem. For example, Carabidae (Hůrka et al. 1996), Staphylinidae (Boháč 1988, 1990, Boháč et al. 2006), Curculionidae (Strejček 2001, Stejskal 2006), Diptera (Frouz 1999, Povolný and Šustek 1983a, 1983b), Psocoptera (Holuša 2003), Thysanoptera (Pelikán 1996), Aranea (Buchar 1983) are purposefully used for bioindication in connection with the soil environment. Similarly, centipedes, millipedes and terrestrial isopods represent an important component of soil fauna suitable for evaluation of biotope quality (Bilton 1996, Paoletti and Hassall 1999, Souty-Grosset et al. 2005, Tajovský 2001a, 2001b, Flasarová 2000, Tuf and Laška 2005, Tuf and Tufová 2008).

A general review of the species of centipedes, millipedes and terrestrial isopods occurring in the studied area of the Moravian-Silesian Beskids is presented in Kula et al. (2011). These species are closely tied to the soil environment by their vital signs. In case of centipedes, preference of food – prey (Collembola, Enchytraeidae), which was dependent on occurrence of fungi (Ferlain et al. 2012), was observed. Abundance of terrestrial isopods increased on year-round irrigated areas (Morón-Ríos et al. 2010). In case of millipedes, there is a significant relationship between nutrients in soil and microbial activity, macrofauna facilitates mineralization of nutrients and release of accessible nutrients for plants (Lavelle et al. 1994, Vasconcelos et al. 2013). Humidity is not the only significant factor influencing density of centipedes, millipedes and terrestrial isopods in a landscape. Slope inclination (Mudrick et al. 1994), different chemical properties of soil (Schaefer and Schauermann 1990, Kula and Lazorík 2016), altitude (Ponge et al. 1997, Tajovský 1997, Sterzyńska et al. 2015) different types of forest (Kautz and Topp 1998, Scheu et al. 2003) and level of urbanization (Bogyó et al. 2015) also contribute to differences in their occurrence.

Our work is based on the classification of forest ecosystems developed by Plíva (1987) and modified for application by ÚHUL (2003), which is used as a basis for forest management in the Czech Republic. The basic units of classification are forest sites, which are grouped into forest site complexes according to an altitude and tree species representation, soil type and composition of herbaceous cover (undergrowth synusia) (Viewegh et al. 2003, Viewegh 2004). Based on this classification, basic and long-term frameworks of forest management with respect to natural processes have been developed. A classification unit – forest site complex – is characterized by climatic, pedologic and altitudinal conditions and by composition of plant community (Viewegh et al. 2003).

The objective of the study was to evaluate differences in composition of communities of centipedes, millipedes and terrestrial isopods in certain forest site complexes and their potential usage to bioindication.

Material and Methods

Study area and sites

Permanent research localities (38) were established in forests of the Smrk and Kněhyně massifs along the mountain river Čeladenka in the Moravian-Silesian Beskids Mts. (1.160 km^2) in the northeast part of the Czech Republic. Network of research localities covers an area of 58 km^2 (Figure 1). The area is specific by homogenous medium rich geological subsoil of sandstone and slates of the external and the Magura flysch. The layer of weathered parent material is considerably thick. From the pedological perspective, the area is characterized by a trophic range from oligo-basic soils (Cryptopodzols and Podzols) to eu-mesobasic soils (Cambisol, Rankers) and with a hydric range from soils without hydromorphic influence to soils permanently affected by water (Organosols). The area is typical with high annual precipitation sum (>1,000 mm) that, in synergy with the above mentioned soil types, creates significantly different hydrological situation (the average outflow rate 20–30 m^3·s^{-1}). The climate is characterized by the average annual precipitation of 690–934 mm, the mean annual temperature of 2.6 °C with the minimum in January (–6.1 °C) and the maximum in July (11.7 °C), the absolute temperature minimum (–30.9 °C) and the absolute temperature maximum (29.5 °C) (Lysá hora weather station, 1,323 m a. s. l.). Significantly inclined slopes (average 14–15°) are common. Coherent forest complexes cover up to 70% of the mountain area. Dominant tree species are Norway spruce (*Picea abies* (L.) Karsten) covering 76% and European beech (*Fagus sylvatica* L.) covering 22% of the area; silver fir (*Abies alba* Mill.) shows low representation of 1% and sycamore maple (*Acer pseudoplatanus* L.), silver birch (*Betula pendula* Roth) and European larch (*Larix decidua* Mill.) are interspersed.

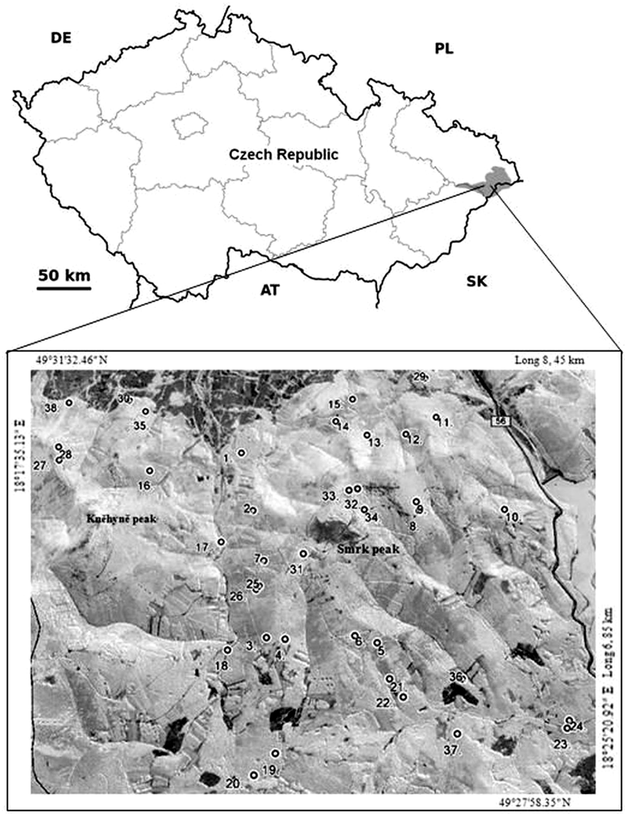

Figure 2. Ordination diagram of environmental variables: comparison of Dim1 vs. Dim2, where Dim1 and Dim2 represent the dimension of tree species (transition from beech to spruce) and quality of soil, respectively. Abbreviotions: Alti = altitude, a. s. l. = above sea level, Athy.fem = *Athyrium felix-femina* (L.) Roth., Ave.flex = *Avenella flexuosa* (L.) Drejer, Beech = *Fagus silvatica* L., C = carbon of soil, Cala.arun = *Calamagrostis arundinacea* (L.), C/N = ratio carbon/nitrogen, cov_herb = coverage of herb, cov_tree = coverage of trees, Dry.expa = *Dryopteris expansa* (C. Presl), Expo = exposition, (eAl, eH, eCa, eMg, eK, eNa) = exchangeable elements of soil, FSC = forest site complex, FVZ = forest vegetation zone, Hum_F = humus form, Luz.luzu = *Luzula luzuloides* (Lam.), Mn = mangenese of soil, Mois.Soil = moisture of soil, N = nitrogen of soil, pH/KCl = soil reaction, Pol.vert = *Polygonatum verticillatum* (L.) All., Ptri.for = *Polytrichum formosum* (Hedw.), Ru.hirt = *Rubus hirtus* W. et K., Skel = skeleton, Sl_inc = slope inclination, Sphag.sp = *Sphagnum sp*., Spruce = *Picea abies* (L.) Karsten., TEP.Air = temperature of air, TEP.Soil = temperature of soil, ToS = type of soil, Vac.myrt = *Vaccinium myrtillus* L.

Sampling of epigeic macrofauna

In order to sample epigeic fauna, the method of pitfall traps was used. In total 190 pitfall traps were installed at 38 research localities (5 traps per stand in span of 10 m, the minimum distance from the edge of the stand corresponded to the tree height). Each FSC had at least two transects, except 4Y habitat 29th. At each research locality, five 4,000 ml jars were placed (glass round-neck-shaped jars with the diameter of 90 mm and the active perimeter for trapping of 283 mm) containing 4% solution of formaldehyde. The whole pitfall trap was buried so that the top edge of the neck was level with the terrain and it was covered with a tin roof (200 × 200 mm) blocking dirt and rainfall. The pitfall traps were set up at the beginning of the vegetation period (1 May) linearly through the middle of the forest with ten-meter spacing and subsequently checked in six-week intervals until the end of the vegetation period (30 October) in the years of 2007–2014. During each check-up, a mixed sample was created of all insects found in the five traps and preserved in 75% ethanol. In the laboratory, each sample was separated into systematic groups and the species were determined. In the years 2007 and 2008, Chilopoda, Diplopoda and terrestrial Isopoda were determined by Ing. Martin Lazorík with professional assistance of RNDr. Mgr. Ivan Hadrián Tuf, Ph.D. and Mgr. Jana Tufová, Ph.D. from the Palacky University in Olomouc. The rest of the samples (2009–2013) were determined by M. Lazorík with necessary consultations. Nomenclature of the determined species was modified according to Tuf, Tajovský (in press) and Tajovský, Tuf (in press).

Environmental data

In order to determine the basic environmental variables used for characteristics of forest communities (Forest site complex – FSC), it was necessary to obtain climatic, pedological and phytocoenological data from the studied localities. Climatic data were obtained from automatic microclimatic stations MeteoUNI (30 pcs) with temperature sensors and soil moisture sensors VIRRIB. Weather stations were mounted on trees in the middle of the line of pitfall traps. Each station measured air temperature (2 m above ground), soil temperature in A and B horizons and soil moisture in A horizon as well as in B horizon at 60 min intervals (Lazorík and Kula 2015).

The A horizon is the topmost mineral horizon, often referred to as the ‘topsoil’. This layer generally contains enough partially decomposed (humified) organic matter to give the soil a colour darker than that of the lower horizons. The B horizons form below an A horizon and they have undergone sufficient changes during soil genesis, such that the properties of their original parent material are no longer discernible. The B horizon is commonly referred to as the “subsoil”. In humid regions, B horizons are the layers of maximum accumulation of materials such as silicate clays, iron (Fe) and aluminium (Al) oxides, and organic material.

Weather stations were in operation during the whole research period (4/2007 – 20/2015). The pedological research was carried out in the year of 2010. A soil pit was excavated at each locality in order to determine the type of soil; at the same time, soil samples were collected from the certain horizons for laboratory analyses. Values of active (pH H_2O) and exchangeable (pH KCl) soil acidity were determined by potentiometry using a digital pH meter (Zbíral 1995). From air-dried soil samples, free of coarse particles, total nitrogen and carbon were determined after fine grinding or comminution (Zbíral et al. 1997). Available nutrients (P, Mg, K and Ca) in a humus horizon (H) were determined after extraction using the method of Göhler (Soukup et al. 1987) and in an organomineral horizon (Ah) after extraction using the method of Mehlich III (Mehlich 1984, Zbíral et al. 1997).

The distance between pitfall traps and soil sampling excavation was 10 – 15 m below line transect of the pitfall traps. Complete phytocoenological research (species spectrum and coverage of undergrowth synusia) in all localities was performed in 2011.

Explanation of abbreviations: Abund = abundance, Alti = altitude, a. s. l. = above sea level, Beech = coverage of *Fagus sylvatica,* C = carbon content, Cala.aru = coverage of *Calamagrostis arundinacea*, C/N = ratio of carbon content and nitrogen content, cov_tree = coverage of trees, cov_herb = coverage of herbs, Dry.expa = coverage of *Dryopteris expansa*, eAl, eH, eCa, eMg, eK, eNa = contents of exchangeable elements in soil, Expo = exposition, FSC = forest site complex, FVZ = forest vegetation zone, Hum_F = humus form, Moist.Soil = soil moisture in the A horizon, Mn = content of manganese oxide in soil, N = nitrogen content, pH/KCl = soil reaction determined in KCl solution, Sl_inc = slope incline, Skel = skeleton content, Spruce = coverage of *Picea abies*, TEMP.Air = air temperature at 2 m above ground level, TEMP.Soil = soil temperature in the A horzion, ToS = type of soil, Vac.myrt = coverage of *Vaccinium myrtilus*, Year = year of sampling.

Characteristics of forest site complexes

Due to the extensity and complexity of forest site complex (FSC) characteristics, only the FSCs occurring at the research localities on the territory of the Moravian-Silesian Beskids were described. Certain FSCs are characterized by undergrowth synusia (herbaceous layer) and tree species representation (Viewegh et al. 2003). The total captured population was spread in 12 groups of forest site complexes. Further, we added possible threats to stability of the studied ecosystems, which may also influence the animals (Table 1).

Statistical analysis

For the purpose of statistical processing, data obtained during field research were input into a data-

Table 1. Characteristics of the selected forest site complexes (FSCs)

FSC	Name	Latin name	Natural tree species (%)	Target tree species (%)	Major herbal species	Distribution	Factor threat
4S	Nutrient-medium Beech	*Fagetum mesotrophicum*	beech 80, silver fir 20, (beech 100, silver fir + admixture)	spruce 70, beech 20, larch10, db+ admix., jd+admix.	*Galium rotundifolium, Calamagrostis arundinacea, Luzula luzuloides, Oxalis acetosella, Dentaria bulbifera, Poa nemoralis, Epilobium montanum, Polytrichum formosum, Viola reichenbachiana.*	Plains, slopes, ravines; on various rocks, often with weak clay overlays; higher uplands, highlands	Insignificant
5S	Nutrient-medium Fir-Beech	*Abieto-Fagetum mesotrophicum*	silver fir 50, beech 50, sycamore maple+admix.	spruce 70, silver fir 10, beech 20, larch+admix.	*Athyrium filix femina, Maianthemum bifolium, Milium effusum, Avenella flexuosa Pleurozium schreberi, Polytrichum formosum, Prenanthes purpurea.*	In upper parts as well as in bases of slopes, mostly fresh ravines, alternatively mountain-ridges; various sub-soil of poor rocks; area of highlands and lower mountain areas	Significantly by wind and snow (Norway spruce); medium by weed (impossibility of natural rejuvenation)
6S	Nutrient-medium Spruce-Beech	*Piceeto-Fagetum mesotrophicum*	spruce 30, beech 40, silver fir 30	spruce 70, silver fir 20, beech 10, larch+admix.	*Luzula luzuloides, Calamagrostis arundinacea, Luzula pilosa, Calamagrostis villosa, Maianthemum bifolium, Melica nutans, Plagiomnium affine, Hieracium murorum, Vaccinium myrtillus.*	Upper and lower parts of slopes; ridges and hollows; highlands and mountain areas; various sub-soils	Medium by weed, significantly by wind and shnow
7S	Nutrient-medium Beech-Spruce	*Fageto-Piceetum mesotrophicum*	spruce 70, beech 20, silver fir 10, sycamore maple+admix.	spruce 80, silver fir 10, beech 10, sycamore maple+admix.	*Maianthemum bifolium, Calamagrostis villosa, Polytri-chum formosum, Avenella flexuosa, Dryopteris dilatata Senecio nemorensis, Festuca altissima Vaccinium myrtillus, Luzula sylvatica, Gentiana asclepiadea, Huperzia selago.*	Mostly on slopes, less on plains; in mountain areas, exceptionally also in the highest highlands; on various sub-soils	Medium by weed, significantly by wind and ice
4Y	Skeletal Beech	*Fagetum saxatile*	beech 60, sessile oak(stunted) 20, silver fir 10, (scots pine, silver birch)10	scots pine 70, beech 30, spruce + admix.	*Avenella flexuosa, Luzula luzuloides, Oxalis acetosella, Mycelis muralis, Veronica officinalis.*	Over-pressed only exceptionally at uplands and at sunny slopes of highlands	Strongly by erosion, significantly by weed
5Y	Skeletal Fir-Beech	*Abieto-Fagetum saxatile*	beech 70, silver fir 20, silver birch 10, scots pine+admix., spruce+admix.	spruce 50, beech 30, silver fir 10, silver birch 10	*Calamagrostis arundinacea, Luzula luzuloides, Avenella flexuosa, Oxalis acetosella, Dicranum scoparium, Poa nemoralis, Dryopteris carthusiana, Polytrichum formosum, Dryopteris dilatata, Rubus fruticosus agg., Vaccinium myrtillus.*	In highlands, foothills also in lower mountain locations on boulder, rubble slopes, rock rock lumps and on ridges	Strongly by erosion, medium by snow, mildly by soil degradation
5A	Stony-colluvial Sycamore-Beech	*Acereto-Fagetum lapidosum*	beech 50, silver fir 30, sycamore maple 20, smooth elm+admix., European ash+admix.	spruce 50, silver fir 10, beech 20, sycamore maple 10, smooth elm 10.	*Hedera helix, Poa nemoralis, Hordelymus europaeus, Rubus hirtus, Melica uniflora, Rubus idaeus, Mercurialis perennis, Senecio ovatus, Oxalis acetosella, Stachys sylvatica, Actea spicata, Symphytum tuberosum, Dentaria glandulosa, Urtica dioica.*	Alluvial levees of mountain areas (floods from spring snow melting and summer cloudbursts) and spring with flowing water	Strongly by erosion, significantly by weed
5L	Montane Ash-Alder	*Fraxineto-Alnetum montanum*	speckled alder 80, spruce 20, sycamore maple+admix. (nižší polohy red alder+admix., European ash+)	speckled alder 80, spruce 20, silver fir+admix.	*Mentha longifolia, Petasites albus, Myosotis palustris, Stellaria nemorum, Ranunculus flammula, Aconitum variegatum, Ranunculus platanifolius, Circaea alpina, Ranunculus repens, Stachys sylvatica.*	In highlands and lower mountain locations; on rich and medium rich sub-soil; slopes, ridges, ravines	By periodic floods, erosion, strongly by snow, ice, weed
5F	Slope-stony Fir-Beech	*Abieto-Fagetum lapidosum mesotrophicum*	beech 60, silver fir 40, sycamore maple+admix., smooth elm+admix.	spruce 70, silver fir 10, beech 10, sycamore maple 10, smooth elm+admix.	*Impatiens noli-tangere, Carex sylvatica Maianthemum bifolium, Dentaria bulbifera, Dentaria glandulosa, Polygonatum verticillatum, Dryopteris carthusiana, Rubus hirtus, Dryopteris filix mas, Senecio ovatus*	Shadowy rocky slopes and ridges in areas of highlands; valley slopes and ravines in higher uplands	Slightly by wind (blowdowns), medium by snow (breaks) and weed, significantly by erosion
5B	Nutrient-rich Fir-Beech	*Abieto-Fagetum eutrophicum*	beech 60, silver fir 40, sycamore maple+admix., spruce+admix.	spruce 70, silver fir 10, beech 20, sycamore maple+admix.	*Petasites albus, Carex sylvatica, Rubus hirtus, Dentaria bulbifera, Sanicula europaea, Dentaria enneaphyllos, Senecio ovatus, Dryopteris filix mas, Senecio nemorensis, Festuca altissima, Solidago virgaurea, Galeobdolon luteum, Urtica dioica, Galium odoratum, Vinca minor*	Highlands (in inversion locations and lower); basis of slopes and plains; overlays of clay on various sub-soils	Strongly by weed, snow (blowdowns and breaks), wind blowdowns (disproportion of crown and roots)
6O	Nutrient-medium Spruce-Fir	*Piceeto-Abietum variohumidum mesotrophicum*	beech 20, silver fri 50, spruce 30	spruce 70, silver fri 30, beech+admix.	*Calamagrostis arundinacea, Homogyne alpina, Vignea brizoides, Maianthemum bifolium, Deschampsia caespitosa, Mycelis muralis, Dryopteris dilatata, Pleurozium schreberi, Soldanella montana, Vaccinium myrtillus.*	From highlands to foothills and mountain areas; on slopes and plains with various (most often) rich sub-soils	Strongly by wind, significantly by snow, waterlogging, grassy weed
6O/R	Nutrient-medium Peat Spruce	*Piceetum turfosum mesotrophicum*	spruce 100, silver fri+admix., alder+admix.	spruce100, alder(fir)+admix.	*Impatiens noli tangere, Calamagrostis villosa, Luzula pilosa, Caltha palustris Luzula sylvatica, Vignea remota Lycopodium annotinum, Circaea alpina, Dicranum scoparium Equisetum sylvaticum*	In mountains and highlands (700 – 1150 m a.s.l.) in flat ravines and lowlands, on spring slopes and slope breaks	Strongly by waterlogging, wind, medium to strongly by weed, ice, medium by snow

base in a matrix shape of independent variables (environmental data) and a matrix of dependent variables (representation of captured species). Firstly, basic data were tested for statistical processing, mean values of variance and outliers were determined. Considering the high number of environmental factors, the objective was to determine those factors that influence the dependent variables with sufficient power (weight). This was used for decision about significance of environmental factors in the follow-up analyses. Non-metric multidimensional scaling (NMDS) according to NCSS 10 Trial 7-day Version software was used as a basic statistical analysis. Basic trends and gradients, along which the determinative variability is concentrated, were searched by the NMDS analysis (Haruštiaková et al. 2012). A number of ordination axes was determined, explaining at least 70% of the variability of environmental variables. The minimal stress value in NMDS and also the minimal changes of stress between the relationships were set to 0.00001. Only the first three axes (dimensions) were used. Subsequently, using the principal component analysis (PCA), a correlation coefficient matrix of important environmental factors was generated.

During testing of influence of two sets of variables, data in the matrix of independent environmental variables (e.g. cov_herb, eMg, eCa, FSC, Cala.aru, Skel, Sl_inc, FVZ, Expo) and in the matrix of dependent variables were confronted. The canonical correspondence analysis (CCA), which uses multidimensional regression in order to determine the linear combination of variables, best explaining inertia of the ordination score obtained from dependent variables, was applied. The power of a permutation test was used in order to test hypotheses in CCA. The statistics itself was realized by the software CANOCO 4.5 for Windows, which offers an option of test power analysis using the Monte-Carlo permutation test with 999 permutations (Lepš and Šmilauer 2003). Function “forward selection” was used in order to put to the truth the power of test in certain environmental variables, where the first eigenvalue is compared with corresponding statistics obtained from random data permutations. The results of CCA were an ordination diagram, in which species as well as samples were represented by points and quantitative variables represented as vectors.

The final objective of the analysis was to determine the variance of the trapped species according to the FSC, in which they were found. Since the factor of the forest site complex was classified as significant by the previously applied methods of multidimensional comparison, single-factor ANOVA from software package STATISTICA 10.0 was used for the stated hypothesis about inequality of variance of certain measured localities. Considering statistically significant variance, multiple comparison by the Tuckey HSD test of homogenous groups and subsequently also comparison of the level of significance were carried out. The result was a comparison of the variability of variance in certain FSC and determination of the statistically significant FSC.

Indicator value

In order to determine indicator values for certain species of centipedes, millipedes and terrestrial isopods, the method IndVal (*indicator value)* according to Dufrene and Legendre (1997) was used. This method is based on combination of relative abundance of certain species with relative frequencies of occurrence at different sites. The index reaches its maximum (100%) when all specimens of a given species occur at all sites with a specific forest site complex. The indicator value is calculated by multiplying specificity A_{ij} with the level of fidelity B_{ij} as follows:

$$IndVal_{ij} = A_{ij} \times B_{ij} \times 100$$

where: A_{ij} = N $individuals_{ij}$ / N $individuals_{i}$; N $individuals_{ij}$ is the average number of specimens of species *i* from all areas of FSC *j,* while N $individuals_{i}$ is a sum of average quantities of specimens of species *i* at all FSC; B_{ij} = $Nsites_{ij}$ / $Nsites_{j}$; N $sites_{ij}$ is the number of areas of FSC *j*, in which a species is present, while N $sites_{j}$ is the total number of areas of FSC.

Results

Importance of environmental variables

Gradients enabling to delimit arrangement of a major part of the environmental variables were found. The analysis gives evidence of the fact that environmental variables are not arranged completely randomly but they are structured in space according to certain gradients with various levels of significance (cumulative percentage). Many factors concurrently influence the arrangement of environmental factors. Therefore, further gradients are not results of definite influence of separate variables but of whole groups of variables, often acting in synergy at random. 74.26% of variability arrangement is ordered according to eight axes (Table 2). Generally, objects cannot be ordered so that in the reduced area, the distances between them would be the same as the summed values of distance (dissimilarity). Therefore, a rate is introduced, which, as a simple number, expresses how well the value of objects is explained in the reduced area. The rate is called “stress function” and in our dimensions, it is set by the span of 0.44–0.12 (Table 3). The result of the analysis was also comparison of dissimilarity of the studied environmental factors. The highest similarity exists between TEMP_Air and TEMP_Soil (f = 0.111) and the least similar were Spruce and Beech (f = 1.937), which is well visible on the spatial arrangement (Table 4).

It is possible to explain distribution of environmental variables in a reduced area only to some extent. Therefore, three gradient axes were selected, by which the environmental variables are defined. Axis 1 (Dim 1) explains 17.71% of variability. We can characterize it as a gradient of spruce forests in higher altitudes with occurrence of *Vaccinium myrtilus,* with a higher content of aluminium oxide and higher herbaceous coverage. The value of the gradient decreases towards beech forests with dense canopy of tree layer with occurrence of *Luzula luzuloides* and *Calamagrostis arundinacea.* Generally, it is possible to state that Dim 1 represents a gradient of phytocoenological composition of a forest stand and herbaceous layer (Figure 2).

Axis 2 (Dim 2) appears to be a gradient of the soil environment, where height of surface humus is important, which is linked to the occurrence of *Sphagnum sp.* and the soil type is Histosols. 13.36% of variability is explained by this gradient. Soil moisture with higher content of accessible Ca and with more alkaline pH/KCL is also important. In contrast to that, the gradient decreases at soils with higher content of skeleton and with worse temperature and moisture regime (Figure 3). Axis 3 (Dim 3) explains a gradient of soil nutrition, where the main indicator is the content of carbon and nitrogen in soil. The gradient increases from lower activity of soil biota to higher activity. This axis explains 12.15% of variables, giving the activity of soil biota important position within the forest ecosystem. The assumption is the significant position in the food chain, where microflora community is a basic element, from which the whole coenosis of the ecosystem is derived.

Table 2. Values of the Classical Multidimensional Scaling (CMDS) for determination of significance of the number of dimensions

Multidimensional Scaling Report				
Eigenvalue Section				
Dim No.	Eigenvalue	Individual percent	Cumulative percent	Bar Chart
1	6.16	17.71	17.71	IIIIIIIII
2	4.61	13.26	30.97	IIIIIII
3 (Used)	4.22	12.15	43.12	IIIIII
4	3.34	9.59	52.71	IIIII
5	2.44	7.00	59.71	IIII
6	2.06	5.93	65.65	III
7	1.52	4.37	70.01	II
8	1.48	4.25	74.26	II
Total	34.77			

Table 3. Determination of the level of significance of stress (goodness-of-fit), where the value of stress <0.05 is acceptable and the value <0.01 is considered as good

Non-Metric Iteration Summary Section				
No. Dim's Maintained	Percent Rank	Stress	Why Terminated	Bar Chart of Stress
1	51.19	0.443486	Stress Change	|IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII<<I
2	51.19	0.276950	Stress Change	|IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII<<I
3	51.83	0.185327	Stress Change	|IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII<<I
4	49.44	0.122428	Stress Change	|IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII<<I

Table 4. Determination of the level of residues highlighting real and forecasted differences of the model

Dissimilarity Section			
Row	Column	Actual Dissimilarity	Predicted Dissimilarity
9 TEP_Air	10 TEP_Soil	0.111561	0.010591
20 C	21 N	0.320896	0.027195
12 pH_KCl	15 eCa	0.397849	0.030277
13 eAl	15 eCa	1.820711	0.317562
23 cov_tree	24 cov_herb	1.900272	0.341405
35 Spruce	36 Beech	1.937213	0.355146

Selection of main components of the final model

Based on the information obtained by the NMDS analysis, relationships between the environmental characteristics and the abundance of millipedes, centipedes and terrestrial isopods were tested by the principal component analysis (PCA). All of the monitored environmental characteristics, in which we assume a link to size of population and their mutual interaction, were tested. The final order of correlation coefficients was determined based on the first two axes (SPEC AXIS 1, SPEC AXIS 2), which explain the total of 81.01% of all variables (AXIS1 = 55.15%, AXIS2 = 25.86%) from the total eigenvalue 0.932 (Table 5). From the set of

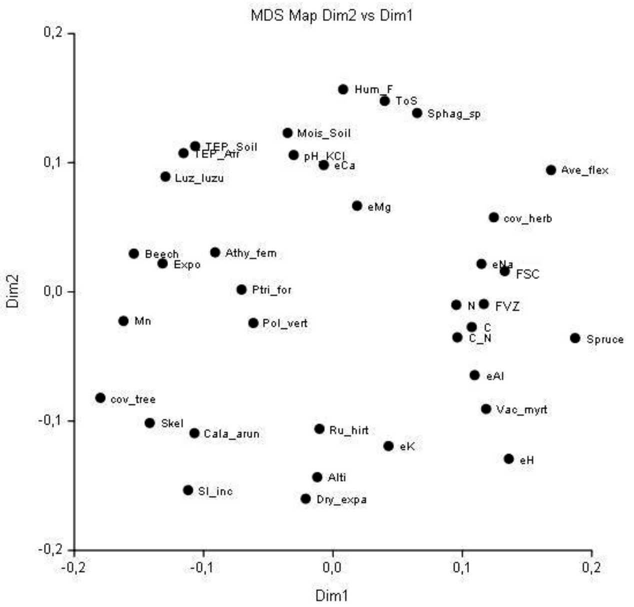

Figure 2. Ordination diagram of environmental variables: comparison of Dim1 vs. Dim2, where Dim1 and Dim2 represent the dimension of tree species (transition from beech to spruce) and quality of soil, respectively. Abbreviotions: Alti = altitude, a. s. l. = above sea level, Athy.fem = *Athyrium felix-femina* (L.) Roth., Ave.flex = *Avenella flexuosa* (L.) Drejer, Beech = *Fagus silvatica* L., C = carbon of soil, Cala.arun = *Calamagrostis arundinacea* (L.), C/N = ratio carbon/nitrogen, cov_herb = coverage of herb, cov_tree = coverage of trees, Dry.expa = *Dryopteris expansa* (C. Presl), Expo = exposition, (eAl, eH, eCa, eMg, eK, eNa) = exchangeable elements of soil, FSC = forest site complex, FVZ = forest vegetation zone, Hum_F = humus form, Luz.luzu = *Luzula luzuloides* (Lam.), Mn = mangenese of soil, Mois.Soil = moisture of soil, N = nitrogen of soil, pH/KCl = soil reaction, Pol.vert = *Polygonatum verticillatum* (L.) All., Ptri.for = *Polytrichum formosum* (Hedw.), Ru.hirt = *Rubus hirtus* W. et K., Skel = skeleton, Sl_inc = slope inclination, Sphag.sp = *Sphagnum sp.*, Spruce = *Picea abies* (L.) Karsten., TEP.Air = temperature of air, TEP.Soil = temperature of soil, ToS = type of soil, Vac.myrt = *Vaccinium myrtillus* L.

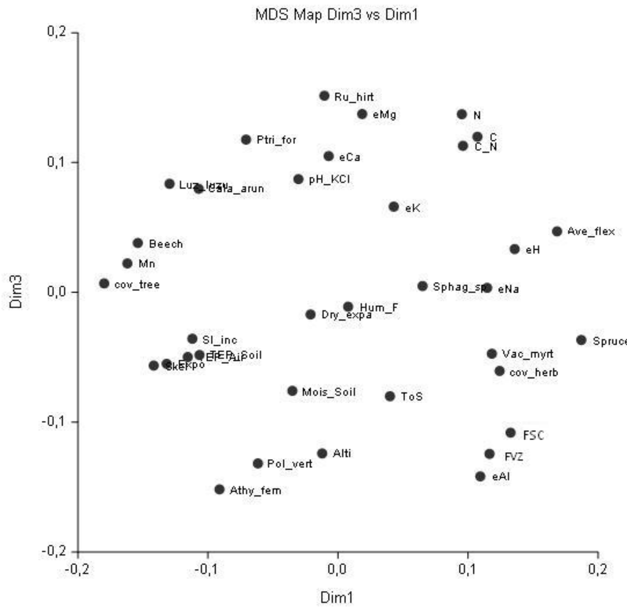

Figure 3. Ordination diagram explaining the change of the forest site complex (Dim1), soil nutrition and chemistry of soil (Dim3). Abbreviotions of environmental variables see in the legend to Figure 2

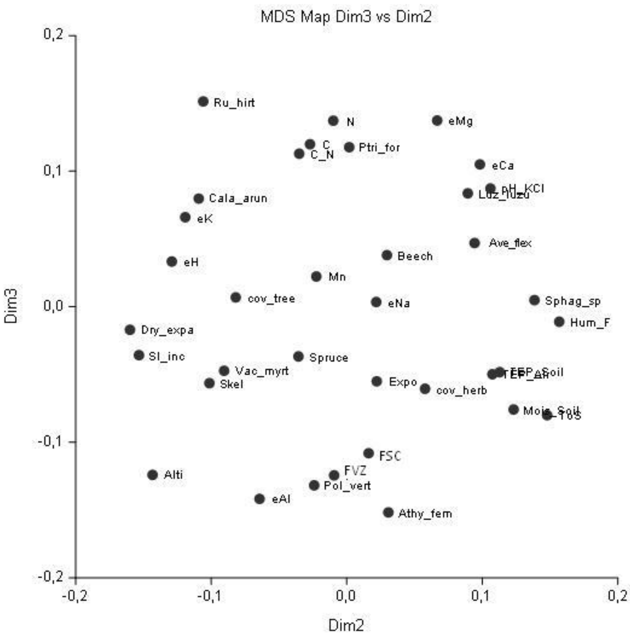

Figure 4. Ordination diagram of the relationship between soil quality (Dim2) and soil nutrition (Dim3). Abbreviotions of environmental variables see in the legend to Figure 2

environmental characteristics, 9 main components were chosen (Expo, Sl_inc, Skel, FSC, FVZ, eCa, eMg, cov_herb, Cala.arun), which were used for further evaluation.

Effect of environmental gradient on millipedes, centipedes and terrestrial isopods

Indirect coordination of types of input data evaluated by the correspondence analysis generated an ordination diagram with data points representing occurrence of species allocated in the whole spectrum of FSCs. It indicates that there is a significant presumption of different species composition in certain FSCs (Figure 5). First two ordination axes explained 63.28% of the final species data.

As a result of the direct gradient analysis of environmental variables data by the Canonical Correspondence Analysis, the first canonical axis was formed explaining 45.74% of the total variability. This high share in explanation was strongly statistically significant ($F = 5.326$, $p = 0.001$). The first canonical axis was well correlated with the environmental data

Table 5. Correlation matrix of selected environmental variables tested by the principal component analysis PCA

**** Correlation matrix ****					
	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	
Abund	-0.4796	0.6950	-0.0543	0.0105	
Year	0.3487	-0.3427	0.1707	0.4878	
Alti	-0.3870	-0.0737	0.1047	0.0290	
Expo	0.6762	0.2597	0.1064	-0.0027	
Sl_inc	0.5023	0.2708	0.3078	0.0238	
Skel	0.4890	0.1124	0.3576	-0.0124	
FSC	-0.6096	-0.2161	-0.2352	0.0203	
FVZ	-0.3646	-0.0099	-0.0145	0.0408	
ToS	-0.1902	-0.1994	0.4321	-0.0127	
Hum_F	-0.1617	-0.2352	0.3063	-0.0170	
TEMP.Air	-0.2687	-0.3701	0.0762	-0.0428	
TEMP.Soil	-0.2664	-0.3696	0.0859	-0.0432	
Moist.Soil	-0.2718	-0.3417	0.1287	-0.0268	
pH/KCl	0.3960	0.1104	0.3891	-0.0292	
eAl	-0.4147	-0.1197	-0.1851	0.0266	
eH	-0.4148	-0.0291	-0.3658	0.0171	
eCa	0.4552	0.1594	0.3963	-0.0229	
eMg	0.4597	0.1432	0.3647	-0.0257	
eK	0.2716	0.0320	0.0447	-0.0286	
eNa	-0.1852	-0.0721	0.2927	-0.0273	
Mn	0.1345	-0.0189	0.4870	-0.0341	
C	0.0606	0.1128	-0.1993	-0.0088	
N	-0.0250	0.0472	-0.1757	-0.0146	
C/N	0.2329	0.1597	-0.1121	-0.0170	
cov_tree	0.0273	-0.0349	0.4140	-0.0056	
cov_herb	0.5477	0.2694	-0.1490	0.0009	
Vac.myrt	-0.3252	0.0756	-0.0998	0.0271	
Cala.aru	0.6286	0.3095	-0.0850	0.0035	
Dry.expa	-0.1360	-0.0881	0.0815	0.0244	
Spruce	-0.3646	-0.0657	-0.3574	0.0279	
Beech	0.1396	-0.0717	0.3529	-0.0360	
	axis 1	axis 2	axis 3	axis 4	Total
Eigenvalues	0.514	0.241	0.103	0.074	0.932
Variables (%)	55.15	25.86	11.06	7.93	100.00

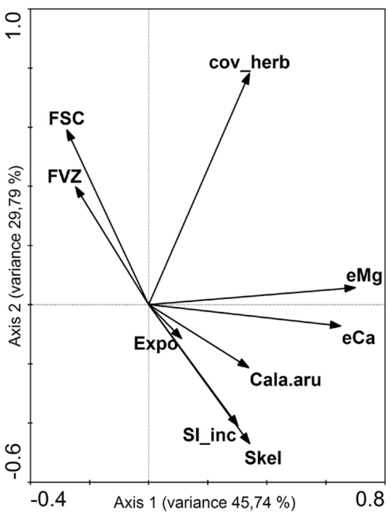

Figure 5. CCA ordination of environmental variables tested on centipede community. Abbreviations of environmental variables see in the legend to Figure 2

(r = 0.561), especially values of variables such as herbaceous coverage, content of ECA, EMG, but above all, with the forest site complex variable. The environmental variables significantly involved in the structure of animal communities were determined by the “forward selection”, where the most important variables were herbaceous coverage, content of calcium and magnesium and a gradient of FSC (Table 6).

Table 6. Environmental variables for millipedes, centipedes and terrestrial isopods: percentages of explained variability, significance and inclusion in manual forward selection (FW) CCA ordination

Variable	Variability explained (%)	*F*	*P*	FW selection
cov_herb	17.3	7.614	0.002	+
eMg	16.72	7.478	0.002	+
eCa	15.37	6.871	0.002	+
FSC	10.86	4.855	0.002	+
Cala.aru	10.23	4.573	0.002	+
Skel	9.46	4.232	0.002	+
Sl_inc	8.31	3.718	0.002	+
FVZ	8.14	3.64	0.002	+
Expo	3.84	1.719	0.01	

Distribution of millipedes, centipedes and terrestrial isopods in forest site complexes

The total captured population was spread in 12 groups of FSCs. Based on the previous analyses it was demonstrated that the FSC factor is sufficiently statistically significant. Thus, the objective was to determine the potential of certain species to characterize certain FSC. ANOVA was used to determine the variance of certain species of the centipede group in the specific FSC. A statistically significant variance was confirmed for *Lithobius erythrocephalus* (F = 1.83; p = 0.04), for which the forest site complex 4S (nutrient-medium beech) is typical. Another indicator species is *Lithodius forficatus,* which demonstrated significant variance not only for FSC 6S (nutrient-medium spruce-beech), but the results of multiple comparison links it also to 4S (nutrient-medium beech) and 5S (nutrient-medium fir-beech), forming a relatively homogenous group of multiple comparison. Also, species *Lithobius mutabilis* occurred more frequently at localities with the FSC 6S (nutrient-medium spruce-beech) (Table 7). As for the representatives of millipedes, *Glomerata connexa* was significant in FSC 5B (nutrient-rich fir-beech) and *Polydesmus complanatus* in FSC 7S (nutrient-medium beech-spruce). From the terrestrial isopods, statistically significant share of *Protracheoniscus politus* was found in 5Y (skeletal fir-beech) and in 5A (stony-colluvial sycamore-beech).

Table 7. ANOVA significance variances of species abundance in relation to forest site complex with multiple comparison

Species	Number ex.	One-way ANOVA Variance	F	p	Tukey HSD Factor FSC	p
Chilopoda						
Cryptops parisi Brölemann, 1920	61	0.100	0.739	0.640		
Geophilus flavus (DeGeer, 1778)	36	0.087	0.419	0.897		
Lithobius austriacus Verhoeff, 1937	128	17.096	1.291	0.288		
Lithobius borealis Meinert, 1868	10	0.321	1.285	0.420		
Lithobius cyrtopus Latzel, 1880	850	3.817	1.622	0.089		
Lithobius erythrocephalus C. L. Koch, 1847	2088	13.897	1.839	0.044	4S	0.04137
Lithobius forficatus Linnaeus, 1758	4428	206.52	17.332	0.000	6S	0.00001
Lithobius microps Meinert, 1868	191	1.038	1.083	0.382		
Lithobius mutabilis L. Koch, 1862	3996	50.162	3.470	0.000	6S	0.02531
Lithobius nodulipes Latzel, 1880	176	1.140	1.539	0.142		
Lithobius pelidnus Haase, 1880	31	0.246	0.640	0.745		
Lithobius tenebrosus Meinert, 1872	57	5.438	3.674	0.005	5S	0.01445
Strigamia acuminata (Leach, 1815)	196	0.707	1.240	0.270		
Diplopoda						
Brachydesmus superus Latzel, 1884	11	0.039	0.318	0.856		
Brachyiulus bagnalli (Curtis, 1845)	11	0.139	0.822	0.473		
Glomeris connexa C. L. Koch, 1847	908	68.488	5.776	0.000	6S	0.00002
Glomeris hexasticha Brandt, 1833	54	6.377	0.602	0.666		
Julus scandinavius Latzel, 1884	81	0.225	1.241	0.286		
Leptoiulus trilobatus (Verfoeff, 1894)	403	3.873	1.591	0.103		
Polydesmus complanatus (Linnaeus, 1761)	472	2.397	2.920	0.001	5B	0.00123
Polyzonium germanicum Brandt, 1837	13	0.151	0.909	0.440		
Isopoda						
Hyloniscus riparius (C. Koch, 1838)	199	104.97	0.922	0.492		
Ligidium hypnorum (Cuvier, 1792)	51	47.066	0.674	0.603		
Protracheoniscus politus (C. Koch, 1841)	1258	175.13	4.259	0.000	5Y	0.00774
Trachelipus ratzeburgii (Brandt, 1833)	205	12.046	1.515	0.166		

This method ignores total variability of population and focuses only on the size of variance, which highlights the importance of the mean value only in case that there is a sufficient number of specimens of the same species occurring at the same locality. Therefore, it was necessary to carry out an analysis based on multiple regression, which reveals trends in data. The matrix of independent variables X (forest site complex) and the matrix of dependent variables Y (representation of species in samples) were subject to the canonical correspondence analysis CCA. For better readability, the results were divided into three ordination diagrams according to the certain groups of species. In the group of millipedes, 48.96% of variability was explained by the first ordination axis and 29.69% by the second ordination axis. We can interpret the result through the first canonical axis as a gradient from 6S (nutrient-medium spruce-beech) /*r* = - 0.275/ up to 5Y (skeletal fir-beech) /*r* = 0.303/. Gradient of the second canonical axis is best characterized by the forest site complex 5A (stony-colluvial sycamore-beech) /*r* = - 0.171/ up to 6O (nutrient-medium spruce-fir). Compared to that, species *Glomerata connexa* and *Brachyiulus bagnalli* had increased occurrence in localities with the forest site complex 5A (stony-colluvial sycamore-beech) and 5B (nutrient-rich fir-beech).

In the centipede group, 40% of the variability was explained by the first canonical axis and 23.53% by the second canonical axis. The total gradient is identical with the group of millipedes. The representation of certain species in the ordination diagram implies that the population is evenly distributed over all localities. Species with high abundance of *Lithobius forficatus, L. erythrocephalus, L. mutabilis* and *L. cyrtopus* occur close to the vector centre, which is caused by their frequent occurrence. Each species is characterized by linearity with different forest site complexes, which is a premise of their possible bioindication usage in specific conditions. A significant one is also species *L. nodulipes,* inclining by its occurrence to 5A (stony-colluvial sycamore-beech) found mostly in mountain ravines and near watercourses. *L. austriacus* confirms occurrence on strongly bouldery soils 5Y (skeletal fir-beech).

For evaluation of the group of terrestrial isopods, the CCA method was also used, resulting in the diagram explaining 61.70% of variability by the first axis and 35.26% of variability by the second axis, which confirms the significant weight of the test. The most abundant species *Protracheoniscus politus* occurred most often in FSC 7S (nutrient-medium beech-spruce). These are the most elevated localities with good hydric regime and medium rich soil nutrition. Other significant species such as *Ligidium hypnorum* and *Hyloniscus riparius* were concentrated in the localities with FSC 6O/R (nutrient-medium peat spruce), which is permanently affected by water (Figure 6).

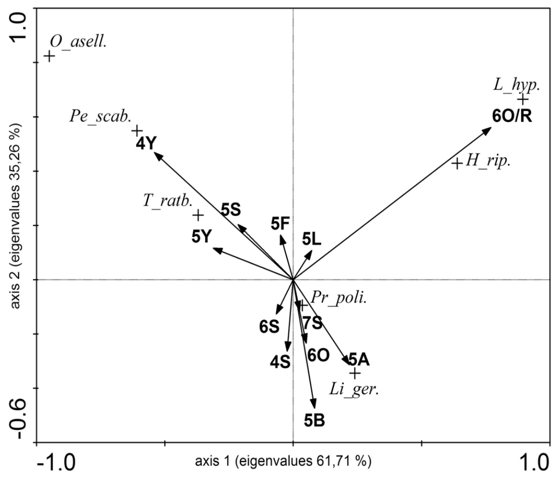

Figure 6. CCA ordination of significance of terrestrial isopods in relation to occurrence in the FSC Abbreviotions of species see in the legend to Table 8

Table 8. Indicating value of different species with different forest site complex. Percentage of the indicator values for each species and forest site complex. EC (Ecological classification for species): Relic species (R): the most stenotopic species are included in this category. These species inhabit exclusively undisturbed habitats with low man-made impact. Adaptable species (A): these species are grouped in communities in nature-close habitats such as different types of forests or meadows. However, they are able to inhabit artificial and man-made habitats typically connected with man-made sites (greenhouses, parks etc.). Eurytopic species (E): the species in this category have the widest ecological valence. E. g. they are frequently found in both forests and non-forested biotopes and also in many man-made biotopes (fields, brown-fields etc.). Synantropic species are inhabiting a wide spectrum of man-made localities (Tuf and Tufová 2008). Species marked in bold represent indicators of the forest sites

Species	Abbrev.	Forest site complex												
		EC	4S	4Y	5A	5B	5F	5L	5S	5Y	6O	6O/R	6S	7S
Chilopoda														
Cryptops parisi Brölemann, 1920	*C_par.*	A	9.2		0.8	6.4	7.7	10.3	19.0				15.2	1.7
Geophilus flavus (De Geer, 1778)	*G_fla.*	E	1.1		9.8	2.4	12.2	29.3	4.3		2.4		9.8	4.9
Geophilus alpinus Meinert, 1870	*G_alp.*	A							16.7					
Lithobius austriacus Verhoeff, 1937	*L_aus.*	A				4.3			3.1	23.8	0.6	2.5	0.1	
Lithobius biunguiculatus Loksa, 1947	*L_biu.*	R										37.5	4.2	
Lithobius borealis Meinert, 1868	*L_bor.*	A	8.0			2.3		18.2	5.0					
Lithobius burzenlandicus Verhoeff, 1934	*L_bur.*	R		22.2					5.6					
Lithobius cyrtopus Latzel, 1880	*L_cyr.*	R	8.8	5.4	8.0	5.0	13.1	9.5	7.2	11.3	3.3	2.1	10.8	15.4
Lithobius erythrocephalus C. L. Koch, 1847	*L_eryt.*	E	11.9	7.6	6.9	7.2	10.3	4.5	9.0	15.0	7.9	2.5	8.7	8.6
Lithobius forficatus Linnaeus, 1758	*L_for.*	E	13.5	5.6	5.4	7.9	11.0	3.6	14.4	4.9	0.5	1.2	24.9	7.0
Lithobius micropodus (Matic, 1980)	*L_mpod.*	A	6.0						1.5	24.3				
Lithobius microps Meinert, 1868	*L_mic.*	E	10.0	4.7	2.8	7.1	6.3	7.9	5.1	5.3	18.9	6.3	5.5	12.6
Lithobius mutabilis L. Koch, 1862	*L_mut.*	E	10.1	1.5	8.2	14.9	8.5	5.0	10.7	5.8	7.7	4.2	15.1	8.2
Lithobius nodulipes Latzel, 1880	*L_nod.*	R		8.5	14.2	2.8	17.5	29.9	3.4	6.8	1.7	1.7	4.5	
Lithobius pelidnus Haase, 1880	*L_pel.*	R	1.8	8.4	4.7	0.5		12.6	0.2	28.0		6.3	0.9	6.3
Lithobius piceus L. Koch, 1862	*L_pic.*	A									50.0			
Lithobius tenebrosus Meinert, 1872	*L_ten.*	A	4.9		2.8	2.1	5.2	8.3	4.0	14.7	1.4	4.2	0.9	24.9
Strigamia acuminata (Leach, 1815)	*S_acu.*	E	0.7	19.3	20.4	12.9	4.8		10.7	10.2	1.6	2.0	1.6	8.0
Strigamia transsilvanica (Verhoeff, 1928)	*S_tran.*	A					4.0	15.9	1.8	14.0				
Diplopoda														
Brachydesmus superus Latzel, 1884	*Br_sup.*	E						6.8	9.1			13.7	1.5	13.7
Brachyiulus bagnalli (Curtis, 1845)	*Br_bag.*	A				6.8				8.0			48.5	
Glomeris connexa C. L. Koch, 1847	*Gl_con.*	A	3.9	2.7	22.1	14.4	6.7	1.7	6.3	6.4	1.4	1.1	23.1	
Glomeris hexasticha Brandt, 1833	*Gl_hex.*	A	1.7			2.9	14.2			2.6			9.1	
Glomeris klugii Brandt, 1833	*Gl_klu.*	A	22.2										5.6	
Glomeris pustulata Latreille, 1804	*Gl_pus.*	A											16.7	
Haasea flavescens (Latzrl, 1884)	*Ha_fla.*	R	29.3											6.0
Julus scandinavius Latzel, 1884	*J_scan.*	E	15.6	8.3	0.5	1.0	16.6	2.4	3.7	8.3	2.1	2.1	14.4	
Leptoiulus trilobatus (Verfoeff, 1894)	*Le_tri.*	A	4.2	7.3	11.5	10.0	13.2	0.9	9.7	8.8	3.2	0.9	16.1	13.2
Polydesmus complanatus (Linnaeus, 1761)	*Po com.*	E	4.8	8.6	0.4	5.3	1.3	9.5	9.3	7.0	7.6	7.9	13.9	23.7
Polydesmus denticulatus C. L. Koch, 1847	*Po_den.*	E												50.0
Polyzonium germanicum Brandt, 1837	*Py_germ.*	A			10.0							15.0	20.0	
Isopoda														
Hyloniscus riparius C. L. Koch, 1844	*H_rip.*	E			4.1	0.1	0.6	1.1		0.5		43.4	0.1	
Ligidium germanicum Verhoeff, 1901	*Li_ger.*	R			33.3									
Ligidium hypnorum (Cuvier, 1792)	*L_hyp.*	E	0.4				0.5	2.0				46.3		
Lepidoniscus minutus (C. L. Koch, 1838)	*Lp_min.*	A		33.3										
Oniscus asellus Linnaeus, 1758	*O_asell.*	E		100										
Porcellio scaber Latreille, 1804	*Pe_scab.*	E		89.7			2.1						0.3	
Protracheoniscus politus (C. Koch, 1841)	*Pr_poli.*	A	6.5	9.2	28.8	6.4	3.9	1.0	0.5	23.4	1.0	5.8	2.0	0.2
Trachelipus ratzeburgii (Brandt, 1833)	*T_ratb.*	A	1.7	57.0	1.7	0.2	4.2	0.5	1.0	18.6			0.6	

Indicator value

Considering the previous method based on species dominance, it was necessary to extend knowledge of the species occurring frequently but bound to a specific biotope by their occurrence. Therefore, method IndVal was used, which evaluates the overall representation of a species in biotopes. The basic criterion for selection of a bioindicating species is its sufficiently frequent occurrence with a rather rare representation in the given biotope. The most significant bioindicating species was *Lithobius nodulipes* in biotope FSC 5L (montane ash-alder). This species was distributed over ten biotopes with the total number of 176 specimens, but with the most significant indicating value in 5L (Table 8). Another significant species was *L. pelidnus* with the indicating value in biotope FSC 5Y (skeletal fir-beech).

Discussion

This study confirms that it is possible to use representatives of epigeic fauna of millipedes, centipedes and terrestrial isopods to bioindicate relatively permanent forest ecosystems. Some authors suggest comparable differences in community composition of epigeic animals in relation to the site (Scheu et al. 2003, Grgic and Kos 2005, Jabin 2008, Golovatch and Kime 2009, Stašiov et al. 2012, Bogyó et al. 2015, Sterzyńska et al. 2015). Using the representatives of millipedes, centipedes and terrestrial isopods groups seems to be particularly significant because they have close ties with soil, herbaceous cover as well as tree coenosis due to their ecology. We confirmed this also via the correlation matrix of significance (Table 5), where coverage of the herbaceous layer and the tree layer represent a significant factor. This is related to quality of the environment under vegetation, such as litter layer and associated nutrition supply (Jabin 2008, Ferlian et al. 2012), humidity and associated microclimate (Tajovský 1997, Grgic and Kos 2005, Sterzyńska et al. 2015). During multidimensional scaling, two main directions of distribution of the explained variables were found, where the first axis of the dimension is determined by quality of the tree (herbal) environment and the second dimension by quality of the soil environment. These two dimensions are closely related and, thus, we can assume that in case of change of the trees (herbaceous) environment, change in the soil environment will occur. These results are in consent with the reports about changes after coverage removal through deforestation (Scheu et al. 2003, Magura et al. 2015), and alternatively through civilisation pressure (Bogyó et al. 2015). Occurrence of plants in association with wood species is interesting. Beech forests are characteristic by occurrence of *Luzula luzuloides* and spruce forests by representation of *Vaccinium myrtillus* and *Calamagrostis arundinacea.* Kula and Lazorík (2015) pointed out differences in composition of millipede, centipede and terrestrial isopod communities in beech and spruce stands. From the overall perspective, results are significant and certain species are distributed over all forest site complexes. In case of millipedes, several species are concentrated around the vectors 5Y and 4S, which indicates medium rich to poor soils with higher skeleton content but with good hydric regime. *Polydesmus denticulatus* was an interesting species that almost exclusively occurred in the highest localities 7S with prevailing higher air humidity. These localities are characteristic by occurrence of strong layer of non-decomposed organic matter with presence of *Vaccinium myrtillus* and prolonged snow cover. Tajovský (1997) found this species in the subalpine range in the Hrubý Jeseník Mts. the the altitude of 1,230 – 1,290 m a.s.l. Stašiov et al. (2012) stated it under Grey alder (*Alnus incana* (L.) Moench), which is a tree species of moist mountain ravines. Reaction of *Glomeris connexa* is also interesting, as it inclines to vectors 5A and 5B, which are placed at medium altitudes with rich nutritious soil and sufficient moisture close to mountain streams and valleys. *Polyzonium germanicum* is a characteristic species that demonstrated inclination to occurrence at FSC 5L (montane ash-alder) with occurrence of *Alnus incana.* These localities are characteristic by spring flooding from melting snow and summer cloudbursts. Sterzyńska et al. (2015) reported the same results in their work, where 35 specimens were found in medium altitudes with Caltho-Alnetum forest stand with natural hydric regime. Increased occurrence was also observed in a waterlogged alder stand in Białowieża Primeval Forest in Poland (Tajovský and Wytwer 2009).

The centipede group shows wide occurrence in all vectors representing forest site complexes. This is a sign of great potential of using these species as the bioindicators of specific natural conditions. From the most often occurring species, *Lithobius forficatus* inclines to FSC 5L (montane ash-alder), which represents montane floodplain. Furthermore, *L. erythrocephalus,* linearity of which corresponds with vector 5Y (skeletal fir-beech), and *L. mutabilis* have the values close to vector 5B (nutrient-rich fir-beech) representing the richest natural site with optimal hydric and nutrition regime within the studied area. Compared to that, *L. austriacus* is closely bound to occurrence of boulders and skeleton, with acid soil reaction and susceptibility to desiccation. There is interesting occurrence of species *L. microps,* which was found in FSCs 6O (nutrient-medium spruce-fir) and 6O/R (nutrient-medium peat spruce) with higher moisture content and starting peat formation processes. The terrestrial isopod group is more comprehensive due to lower number of species and at many localities it is missing. The most significant bioindication potential is in species *Hyloniscus riparius* and *Ligidium hypnorum,* which are closely linked to FSC 6O/R (nutrient-medium peat spruce). *Protracheoniscus politus*, which belongs to the eurytopic species with wider ecologic valence (Tuf and Tufová 2008), occurred in all forest site complexes with inclination to vector 5A (stony-colluvial sycamore-beech), where it was found even in the highest altitudes. These results are confirmed by Sterzyńska et al. (2015), who reported that occurrence of *Protracheoniscus politus* correlated neither with groundwater level nor with altitude. *Trachelipus ratzeburgii* avoided waterlogged peat localities and its most frequent occurrence was in FSCs 4Y (skeletal beech) and 5Y (skeletal fir-beech). These localities are strongly threatened by erosion and suffered from significant soil degradation, and mildly desiccated soil (Plíva 1978). *Oniscus asellus* belongs to the species with low abundance, only one specimen was trapped in FSC 4Y (Skeletal Beech). Another species is *Porcellio scaber,* of which 12 specimens were caught and the highest number occurred in FSC 4Y, but also in FSC 5F (slope-stony fir-beech), which is significantly threatened by erosion. A significant species with bioindicating value was *Lithobius nodulipes*, which was bound to FSC 5L (montane ash–alder). This species belongs to the relict representatives living in Southeast Europe (Dobroruka 1959, Folkmanová et al. 1955). It proved to be indication-significant in the biotope of mountain streams and springs in the studied area, which corresponds with the data from Spitzer et al. (2007). It was also found in spruce forests of the top parts of the Šumava Mts. (Tajovský 2001c). *Lithobius pelidnus* belongs to the species with the indication value in FSC 5Y (skeletal fir-beech). It is a rarely found centipede in foothill and mountain locations of Central Europe (Laška 2004, Tuf and Tufová 2008). It likes to stay on tree trunks and branches with rugged bark, where it was found in winter and also during the vegetation period (Summers and Uetz 1979, Spitzer et al. 2010, Kula and Lazorík 2014). The results imply significant potential of using certain species of millipedes, centipedes and terrestrial isopods for bioindication of relatively permanent forest ecosystems. Recent publications focus on the issue of population dynamics of these species (Bogyó et al. 2015, Sterzyńská et al. 2015, Magura et al. 2015, Kula and Lazorík 2015) and research of the impact of global changes. Realization of field research is difficult and thus some of the site conditions were not included such as localities with occurrence of soils on limestone. Considering the results obtained by the PCA, it is clear the contents of Ca and Mg are very significant factors. Therefore, it is necessary to study the population dynamics and composition of species on limestone localities with similar climatic characteristics. Considering that climatic factors (air temperature and soil temperature) are not significant for distribution of millipedes, centipedes and terrestrial isopods (Jabin 2008, Lazorík and Kula 2015), with the aim to obtain comparable data, it is necessary to focus on selection of localities according to altitude (Sterzyńská et al. 2015) and tree species composition (Stašiov et al. 2012, Kula and Lazorík 2015). After obtaining sufficient knowledge about distribution of certain species it will be possible to use the structure of the coenosis in forest management for the selection of optimal tree species composition. Since the reaction of edaphic fauna to ecosystem changes is faster than the reaction of undergrowth, it is possible to use it for bioindication of site conditions.

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