Comparison of habitats of the rare fungus *Pluteus fenzlii* between Białowieża Virgin Forest (Poland) and thermophilous forests (Slovakia)

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Abstract. *Pluteus fenzlii* is a rare Eurasian lignicolous fungus, an iconic bright yellow species that attracts attention. Its habitat in the Białowieża Virgin Forest, Poland, is dominated by *Carpinus betulus* with admixture of *Quercus robur*, *Tilia cordata* and *Picea abies*, with an herb layer typical for the *Carpinion betuli* alliance. In Slovakia, the country hosting the highest number of localities worldwide, *P. fenzlii* prefers closed canopy of thermophilous forest with dominance of *Quercus cerris* and adjacent *Quercus robur* agg., *Q. petraea* agg., *Carpinus betulus* and *Tilia cordata*. In the Natura 2000 classification this vegetation belongs to habitat 91M0, Pannonian-Balkanic Turkey Oak-Sessile Oak forests, and priority habitat 91G0, Pannonic woods with *Quercus petraea* and *Carpinus betulus*. The Slovak localities can be assigned to the mycosociological community *Boleto (aerei)–Russuletum luteotactae*, typical for thermophilous oak forests of Southern Europe and extrazonal areas in Central Europe. The presence of *P. fenzlii* at the isolated Białowieża locality could represent either a remote site of its present occurrence or a remnant of its former distribution, connected with the relic occurrence of thermophilous vegetation in Białowieża where continental oak forests have already disappeared.

Key words: Central Europe, threatened fungi, habitat, thermophilous vegetation, fungal community, ordination

Introduction

*Pluteus fenzlii* is a rare Eurasian lignicolous fungus known from only six countries in Europe (Holec et al. 2018). This remarkably yellow annulate species grows on dead wood of broadleaved tree species. It is an iconic species that attracts attention. It usually occurs in hilly areas with more or less natural broadleaved forests, mostly meso- and thermophilous ones, within the transitional zone between hornbeam (alternatively beech) and oak woodlands. However, the species occurs in a wide geographical area and transitional ecological niches in Europe. From west to east, it occurs in foothills of the French Pyrenees in northern basophilous mountain beech forests belonging to the suballiance *Scillo lilio-hyacinthi-Fagenion sylvaticae* and ravine ash forests belonging to the association *Iso-pyro thalicroidis-Quercetum roboris* from the alliance *Fraxino-Quercion roboris* (Corriol & Moreau 2007). The easternmost European locality is in pine-dominated forests with admixed deciduous trees on carbonate rock covered by loam in the vicinity of the Volga River, Samara region, Russia (Malysheva et al. 2007). The northernmost locality in Central Europe is the Białowieża Virgin Forest in eastern Poland, where *P. fenzlii* grows in hornbeam-dominated deciduous forest of the association *Tilio cordatae-Carpinetum betuli* on glacifluvial deposits. In the south it is currently reported from Hungary as occurring in acidophilous beech forests of the association *Luzulo-Fagetum* on andesite bedrock and in thermophilous oak forests on sandstone, andesite and alluvial deposits of slightly acidic loess and clay (Holec et al. 2018).

As our previous detailed paper on *P. fenzlii* was focused on its mycological characterization (Holec et al. 2018), the present work describes and discusses in detail the vegetation data of its northernmost isolated locality in Białowieża in a comparison with more diverse localities in Slovakia (the country hosting the highest number of...
its localities worldwide), supplemented with notes on the fungal communities at Slovak sites.

**Methods**

The vegetation of all known Slovak localities of *P. fenzlii* (for details on their geography see Holec et al. 2018) was sampled by the first author from May 30 to June 1, 2017 (Table 1). The Polish locality was sampled on September 14, 2016 during other study (Holec et al. 2019). All relevés covered the area around fallen trunks with *P. fenzlii*. Sampling covered areas of ~250 m². The exact coordinates are not published here, in view of the need for strict nature conservation (protection of rare fungal communities from mushroom pickers), but can be obtained from the authors on request. We sampled the tree (*E₁*), shrub (*E₂*) and herb (*E₃*) layers separately using the Braun-Blanquet phytosociological approach (Kent 2012). Cover-abundance of individual species was estimated on a modified ten-degree Domín-Hadač ordinal scale: r (rare, sterile, seedling), 1 (rare, fertile, few individuals, more seedlings, sapling), 2 (several individuals, cover ~1% of relevé area), 3 (more individuals, cover up to 2%), 4 (more individuals, vegetative dispersed, cover up to 5%), 5 (cover 6–15%), 6 (16–25%), 7 (26–50%), 8 (51–75%), 9 (76–100%). Plant names follow Euro+Med (2006–). Names of syntaxa follow Jarolímek et al. (2008) and Matuszkiwicz et al. (2012).

For comparison of our vegetation relevés with the synthesis of higher units of deciduous forests in Slovakia, we compiled a frequency table (Table 1). Diagnostic, constant and dominant species status and values were taken from Jarolímek & Šibík (2008). Diagnostic taxa are ordered to display taxa with the best diagnostic capacity (Φ > 0.5, Chiły et al. 2002). Constant taxa have a percentage frequency of occurrence of more than 25% for classes and more than 40% for alliances, marked “c”. Dominant taxa (bolded) have abundance higher than 50% in at least 3% of the relevés.

Unconstrained gradient analysis was computed to visualize the positions of diagnostic species in Canoco 5 (ter Braak & Šmilauer 2012). Individual localities and centroids of higher vegetation units were passively projected to the ordination biplot.

Fungal communities are discussed with respect to Fellner (1984, 1987, 1988) and Smarda (1972). Lists of fungal species from Slovak localities of *P. fenzlii* were compiled by the second author in collaboration with local amateur mycologists. The Mäsiarsky bok locality was not classified due to insufficient mycological data.

**Results**

In Białowieża National Park, Poland, one relevé was sampled, as we found *P. fenzlii* at one site only (Table 1, Fig. 1A, B). The canopy was formed by *Carpinus betulus* with additional occurrence of *Quercus robur, Tilia cordata* and *Picea abies* in the tree layer. In the shrub undergrowth, only *Carpinus betulus* was rarely present (3%) even though this layer is more represented in the neighbourhood. The herb layer showed average conditions without any significant indication of extreme or different environmental conditions. Species of the herb layer were typical for a higher-level order (alliance *Carpinion betuli* in the Central European concept of the class *Querco-Fagetea*; Fig. 2A, lower left quadrant). Common species of such a hemiboreal forest are typical for both broadleaved and coniferous woods, respectively. At the same site there was a mixture of characteristic species of the alliances *Carpinion betuli* (class *Querco-Fagetea*) and *Piceion excelsae* (class *Vaccinio-Piceetea*). Oxalis acetosella, Gymnocarpium dryopteris, Maianthemum bifolium, Dryopteris dilatata, Milium effusum, Festuca gigantea and Stellaria holostea. The occurrence of nitrophytes (*Urtica dioica, Geranium robertianum*) and clear-cut species like *Rubus idaeus* shows concurrent human and animal influences on the composition and structure of the forest stand both in the past (coppicing, opening) and at present (overgazing by wild game, which is currently frequent in Białowieża).

In Slovakia, *Pluteus fenzlii* preferred closed canopy of broadleaved forests (cover 60–80%) with dominance of *Quercus cerris* and *Carpinus betulus*, and adjacent *Quercus robur* agg., *Q. petraea* agg. and *Tilia cordata* (Table 1, Fig. 3). The shrub layer was relatively open (0–25%), with tree layer species and/or meso-xerophilous shrubs forming self-sustaining bushes along the edges (alliance *Prunion spinosae, class Rhamno-Prunetea*), such as *Crataegus monogyna, C. laevigata, Rosa canina* agg. and *Ligustrum vulgare*. Cover of the herb layer varied between 1% and 60%. The average number of herb species per relevé was 24.6. Some characteristic species (dominant and/or frequent) are important indicators. The dominant grasses are typical of broadleaved forests (class *Querco-Fagetea*) and have a wide ecological niche: *Poa nemoralis, Brachypodium sylvaticum, Dactylis glomerata* subsp. *lobata* and *Melica uniflora*. Similarly, the very frequent forbs *Moehringia trinervia, Veronica chamaedrys* and *Geranium robertianum* occur in various forest units. Mesophilous and meso- to eutrophic shade-tolerant hemicyanophytes played an adjacent role in the undergrowth (Fig. 2A, upper left quadrant; *Viola reichenbachiana, Fragaria vesca, Lamium galeobdolon, Pulmonaria officinalis*). The group of diagnostic species of hornbeam, scree and beech woods (*Melica uniflora, Galium schultesii, Lamium galeobdolon, Galium odoratum, Mycelis muralis*) was present only on a deep scree slope (Mäsiarsky bok Reserve). Other nitrophilous species like *Urtica dioica, Galium aparine, Glechoma hederacea, Geum urbanum* and *Alliaria petiolata* indicate higher nutrient content and/or anthropogenic impacts, additionally with *Impatiens parviflora*, a neophyte originating from Central Asia.

We were able to distinguish two main types of thermophilous woods inhabited by *P. fenzlii* in Slovakia: (i) oak woods on deeper (basic) substrates with loess, pseudogley or clay soils and species-rich basophilous vegetation (with *Corns mas, C. sanguinea, Ajuga genevensis, Lathyrus niger, Mellitis mellisophyllum, Tanacetum corymbosum,*
Figure 1. *Pluteus fenzlii* basidiomata and habitats. A–B – in Białowieża (photo J. Holeč 13.9.2016); C–D – in Slovakia, NNR Boky (photo V. Kunca 15.7.2017 and 24.9.2015); E – Tri chotáre hill (photo T. Kučera 29.5.2017); F – Háj hill (photo T. Kučera 30.5.2017); G – NNR Másiarský bok, photo V. Kunca 20.6.2017.
Vicia cassubica), and (ii) deciduous woods on acidic substrates such as andesite screes, with acidophytes (Fig. 2B, lower right quadrant; Veronica officinalis, Hieracium sabaudum, Silene viscaria). Thermophilous acidophytes occurred on shallow soil on raised andesitic bedrock (Silene nemoralis, Hylotelephium maximum, Genista pilosa, Campanula persicifolia, Verbascum austriacum; only in Boky Reserve, not visualized).

The presence of hygrophilous species of open habitats, such as Persicaria hydropiper, Carex pallescens, Carex remota, C. hirta, Juncus effusus, Lysimachia nummularia and Stellaria media, indicated forest springs and wet depressions (Trichotáre hill).

**Discussion**

**Poland**

**Vegetation characterization.** The development of the structure and composition of forest communities in Białowieża Virgin Forest differs from that of the rest of Central Europe, due to the lack of Fagus sylvatica in the Białowieża region (Faliński 1986). Unlike in Slovakia, we found Pluteus fenzlii in shaded linden oak-hornbeam forest (association Tilio-Carpinetum) with Picea abies admixture (Fig. 1A, B; Holec et al. 2018: Fig. 13). Previous records of *P. fenzlii* in the Białowieża Virgin Forest are not characterized exactly as to the location and vegetation (Gierczyk et al. 2015: forest sections 285B, 284Bd), but most probably originate from a similar habitat (Kwiatkowski 1994). Unlike other areas of hornbeam forest in Central Europe (Ellenberg 1988), the Białowieża forests contain boreal species, ferns and some other species that typically grow in beech forests. In our relevé (Table 1) this is documented by the presence of *Picea abies, Festuca gigantea, Maianthemum bifolium, Oxalis acetosella* and *Trientalis europaea* (the latter outside the relevé) typical for spruce forests, while Dryopteris dilatata, Galeobdolon luteum, Galium odoratum, Gymnocarpium dryopteris, Hordelymus europaeus (outside the relevé) and *Milium effusum* represent typical species of suballiance Eu-Fagetalia (Matuszkiewicz et al. 2012). Very striking is the regular presence of spruce. Unlike the situation in Central European deciduous forests, where spruce is absent in oak forests, in Białowieża it is a very common species, naturally overgrowing lime and hornbeam in the tree layer. The current vegetation is concealed by the expansion of shade-prefering trees like *Carpinus betulus*, documented by a comparative long-term study of permanent plots that began in the 1970s (Kwiatkowska et al. 1997). The most common species of the herb layer currently are Galeobdolon luteum, *Stellaria nemorum, S. holostea, Galium odoratum, Hepatica nobilis, Viola reichenbachiana* and *V. riviniana*. The local absence of many meso- and thermophilous species, which are typical for herb-rich hornbeam woods (alliance Carpinion) in Central Europe, is very striking (Ellenberg 1988). Thermophilous species are slowly disappearing (Carlina acaulis, Łaska 2009), as confirmed by our experience: we have only rarely sampled common thermophilous species such as Betonica officinalis, Convallaria majalis, Daphne mezereum, Lathyrus niger, L. linifolius, Lilium martagon, Melica nutans and Melittis melissophyllum (Holec et al. 2019).

**Holocene history.** The background of Holocene history may provide key information to help explain the common occurrence of boreal and thermophilous species in the Białowieża Virgin Forest. It differs from southern parts of Central and Southeastern Europe not only climatically but also by the absence of altitudinal belts in flat relief, yet the vegetation pattern is determined by the heterogeneous mosaic of soil types overlying glaciofluvial sediments up

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**Figure 2.** Biplots of principal component analysis (PCA), showing the positions of *P. fenzlii* localities (empty circles) in vegetation space (A – 1st and 2nd axes explain 44% of species variance; B – 3rd and 4th axes 24%). The respective higher vegetation units were taken from the literature (underlined; for full names of vegetation units see explanations in Table 1). For full names of plant species see Table 1. Numbers in front of genera refer to vegetation layer (3 tree, 2 shrub, 1 herb = seedlings).
to 800 m deep (Malzahn et al. 2009), which are highly water-permeable and remained frozen relatively long after the retreat of the glaciers (Šafanda et al. 2004; Szewczyk & Nawrocki 2011). This probably allowed numerous postglacial relics as well as boreal and continental species to persist to the present (Kaźmierczakowa & Zarzycki 2001; Adamowski 2009; Pawlaczuk 2009). The tree composition was completed at the turn of the millennium by the expansion of Carpinus (Kupryjano-wicz 2007; Mielecka et al. 2009), supported by past dynamics of fires (Niklasson et al. 2010). The present overgrowth by hornbeam (associated with the falling of the remaining big oak, pine and spruce trees), exacerbated by intensive pasturage or colonization in the past, does not bode well for the future of spruce (and oak). In the long-term perspective, the decline of both oak and spruce threaten the unique mycobiota (Karasiński et al. 2010) of the Białowieża Virgin Forest.

Slovakia

**Vegetation characterization.** The vegetation maps of temperate forests are very heterogeneous in lower vegetation units along the gradients of altitude, soil, exposure, relief, water and nutrients (Bohn et al. 2004). Slovak localities of *P. fenzlii* (Table 1, 10 relevés; Holec et al. 2018: Fig. 13) are located mostly in the transition between the potential vegetation units of hornbeam woods (suballiance *Carici pilosae-Carpinietum betuli*), xerothermic submediterranean oak woods (alliance *Quercion pubescenti-petraeae*) and/or thermophilous oak woodland (ass. *Quercetum petraeae-cerris*, Fig. 1C–E). One locality (Háj hill near Pravica) represents a transition to subcontinental oak forest (ass. *Potentillo albae-Quercetum*, Fig. 1F). The Mäsiarsky bok Reserve is covered by beech rich submontane forests of suballiance *Eu-Fagenion* (Fig. 1G) (Michalko 1986). In the Natura 2000 classification, all this vegetation belongs to habitat 91M0, Pannonian-Balkanic Turkey Oak-Sessile Oak forests, and priority habitat 91G0*, Pannonian woods with *Quercus petraea* and *Carpinus betulus* (Stanová & Valachovič 2010).

Considerable spatial variation and human impacts probably produced the mixture of plant species of different communities in our relevés, especially at the border of hornbeam and thermophilous oak woods. The spatial pattern of thermophilous oak woodland consists of forest and/or a non-forest habitat mosaic where different mesophilous and thermophilous species merge continuously. For example, *Corus mas*, *Sorbus torminalis* and *Cra-taegus monogyna* (Table 1, Háj hill) indicate submediterranean thermophilous oak woods (alliance *Quercion pubescenti-petraeae*), while *Q. cerris*, *Acer campestre* with the forbs *Lathyrus niger*, *Astragalus glycyphyllos* and *Clinopodium vulgare* (Fig. 2B: upper right quadrant) indicate dry mesic oak woods with some acidophilous herbs (alliance *Quercion confertae-cerris*, Jarolímek & Šibík 2008). After finalization of this paper, *P. fenzlii* was found in the Čačinska cerina National Reserve (Fig. 3, empty circle), which is a near-natural forest with predominant occurrence of *Q. cerris*. Several basidiomata were observed by the second author on a fallen decaying trunk of *Q. cerris* on June 1, 2018.

**Vegetation classification.** Although the classification of oak forests does not seem complicated, it is very difficult to impossible to precisely determine our vegetation relevés and to assign them to associations or higher vegetation units. The number of diagnostic species in our relevés is very low in comparison with vegetation syntheses of thermophilous oak forests of larger areas (Roleček 2005, 2007; Purger et al. 2014). There are two possible explanations for this. (i) Regional vegetation studies contain more characteristic, endangered and rare species, because the widely used preferential sampling of phytosociological relevés is based on the researcher’s subjective decision and choice of appropriate relevé plots (Michalcová et al. 2011). Our vegetation sampling, determined by the occurrence of *P. fenzlii*, was closer to a random design of vegetation sampling. Our relevés were sometimes represented by herb-lacking or mixed plots often located in a natural transition of vegetation units or reflecting heterogeneous terrain. As a result, our relevés lack many differential species and in ordination diagram they are positioned in the central part of the biplot (Fig. 2). (ii) In the niche occupied by *P. fenzlii*, average habitat conditions prevail and specialist plant species having higher ecological indicator values are absent. This “biotic filter” exhibits no extraordinary environmental conditions or niche specialization at the level of community structure (van der Maarel 2005; Garnier et al. 2016).

Geographical zonation plays an integral role of dispersal trails in the Hemiboreal (Białowieża), Carpathian, Pontic-Pannonian, subcontinental and submediterranean regions. Southern Slovakia represents the contact zone of the Pontic, Matra and Carpathian biogeographical areas (Bohn et al. 2004). The northern border of the distribution of the Illyrian-Balkan association group is located in southern Slovakia. This vegetation differs from Central European vegetation by its geographically vicariant species (e.g. *Quercus cerris*, *Q. frainetto*, *Fraxinus ornus*, *Castanea sativa*, *Acer tataricum*) (Horvat et al. 1974). The numerical classification of Hungarian, Croatian and Serbian oak forests on loess simplified the complicated regional syntaxonomy (consisting of several local associations described in the past; see Borhidi 1996) by delimiting

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**Figure 3.** Distribution of *Pluteus fenzlii* localities documented by vegetation relevés (●) in Slovakia, (○) new locality from 2018.
Table 1. Vegetation relevés.

| Layer | Tree species | Herb species | Bush species | Shrub species |
|-------|--------------|--------------|--------------|---------------|
| E1    | *Fagus sylvatica* | *Viola rufa* | *Cornus mas* | *Euphorbia cyparissias* |
| E2    | *Acer platanoides* | *Campanula trachelium* | *Polygonatum latifolium* | *Rosa canina* |
| E3    | *Quercus petraea* | *Hieracium sabaudum/racemosum* | *Vincetoxicum hirundinaria* | *Cruciata glabra/laevipes* |
| E4    | *Quercus robur* | *Festuca heterophylla* | *V. hirta* | *Fagion* |
| E5    | *Quercus cerris* | *Brachypodium sylvaticum* | *Polygonatum latifolium* | *Fagion* |
| E6    | *Sorbus torminalis* | *Campanula trachelium/rapunculoides* | *Rosa canina* | *Fagion* |
| E7    | *Ligustrum vulgare* | *Hieracium sabaudum/racemosum* | *Vincetoxicum hirundinaria* | *Fagion* |
| E8    | *Evonymus europaea* | *Hieracium sabaudum/racemosum* | *Vincetoxicum hirundinaria* | *Fagion* |
| E9    | *Ligustrum vulgare* | *Hieracium sabaudum/racemosum* | *Vincetoxicum hirundinaria* | *Fagion* |
| E10   | *Ligustrum vulgare* | *Hieracium sabaudum/racemosum* | *Vincetoxicum hirundinaria* | *Fagion* |

Plant and Fungal Systematics 64(1): 101–110, 2019
Table 1. Continued.

| Species present in 1 or 2 relevés: Hál hill | Bromus racemosus | Convallaria majalis | Euphorbia amygdaloides | Lapsana communis | Mellitiss melissophyllum | Quercus petraea agg. | Ranunculus cuspidatus agg. | Paeonia officinalis | Ajuga genevensis | Galeopsis speciosa | Chelidonium majus |
|------------------------------------------|------------------|--------------------|------------------------|----------------|-------------------------|-------------------|------------------------|------------------|-----------------|------------------|------------------|
| Hál hill | Picea sitchensis (P) | Populus tremula | Prunus spinosa | Quercus petraea juvenile | Vaccinium myrtillus | Vicia cracca | Allium cepa | Symphytum officinale | Veronica spicata | Solidago virgaurea | Scabiosa columbaria | Veronica spicata |
| P. sitchensis | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P. nigra | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P. abies | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P. sitchensis (P) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P. nigra | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P. abies | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Species present in 1 or 2 relevés: Hál hill: Bromus racemosus 1, Convallaria majalis 1, Euphorbia amygdaloides 1, Lapsana communis 1, Mellitiss melissophyllum 5, Quercus petraea agg. juvenile 1, Ranunculus cuspidatus agg. 1, Paeonia officinalis 1, Ajuga genevensis 1, Galeopsis speciosa 1, Chelidonium majus 1, Veronica spicata 1, Solidago virgaurea 1, Scabiosa columbaria 1, Veronica spicata 1.

Explanations

Abbreviations: NNR: national nature reserve, NP: national park, PA: protected area.

Localities in Slovakia: Kromínovské vrchy, Zvolen district, near Budča: NNR Boky 1, alt. 330 m, steep SSE slope, NNR Boky 2, alt. 295 m, steep SE slope. – Krupinská planina, Zvolen district, near Babín: NNR Másiarovský bok, alt. 425 m, steep W slope. – Štiavnické vrchy, Krupina district, near Kráľovcov-Krníkov: Konéty vrch hill, alt. 295 m, gentle NNE slope. – Ostrôžky, Veľký Krtíš district, E of Pravica: Hál hill (415 m) alt. 360 m, gentle W slope. – Juhoslavská kotlina, Lučenec district, near Lúbočany: Pleskotí, alt. 245 m, gentle E slope, Pleskotí hill 2, alt. 295 m, steep E slope. – Juhoslavská kotlina, Poltár district, near Petrovec: Tri chotáre hill (276 m), alt. 240 m, gentle N slope. – Juhoslavská kotlina, Rimávská Sobota district, near Teremčí: Tri chotáre hill: Malá obora protected area, alt. 230 m, gentle NE slope. – Cerová vrchovina, Rimávská Sobota district, near Petrovec: hill (315 m) between Petrovec and Jesitice villages: alt. 290 m, gentle S slope. For details see Holec et al. (2018).

Locality in Poland: Podlasie Province, Hajnówka district, Białowieża NP: alt. 150 m, flat terrain. For details see Holec et al. (2018).

Syntaxa names in columns (bolded, see below) and abbreviations (in parentheses) are followed by the number of processed relevés: cl. Querco-Fagetia Br.-Bl. et Vlieger in Vlieger 1937 (Q), subcl. Fagetalia Pavlovský in Pavlovský et al. 1928: all. Carpinion betuli Isler 1931 (C), all. Tilio-Acerion Klik 1955 (TA), subcl. Fagetalia sylvatica Laquet 1926 (F). Subcl. Quercetalia pubescenti-petraeae Klik 1933: all. Quercion pubescenti-petraeae Br.-Bl. 1932 (Qpp), all. Quercion petraeae Zólyomi et Jakucs ex Jakucs 1960 (Qp), all. Aceri tatarici-Quercion Zólyomi et Jakucs 1957 (AcQ), all. Quercion confertae*-cerris Horvat 1954 (*-petraeae) (Qcc), all. Vaccinio-Piceetum Br.-Bl. in Br.Bl. et al. 1939, all. Piceion excelsae Pawlovský et al. 1928 (Psc). Dominant taxa (bolded) have abundance higher than 50% in at least 3% of the relevés.
six communities of wider rank (Purger et al. 2014). The southern Hungarian localities of \textit{P. fenzlii} belong to the submediterranean \textit{Ruscus aculeatus} type, similarly as in the \textit{P. fenzlii} type area (Holec et al. 2018) in the Fruška Gora Hills, Serbia (Fig. 1B in Purger et al. 2014).

\textbf{Fungal communities.} Fungi and their communities are more or less dependent on plants but they are necessary for the existence of most phytocoenoses and also affect their composition (Winterhoff 1992), being symbionts of most plants (parasites, mycorrhizal partners, endophytes) and decomposers of their biomass. Most fungal communities tend to be closely connected with certain plant communities.

Fungal communities of thermophilous oak forests in Central Europe are very specific (Fellner 1988). From the mycocoenological point of view, all evaluated localities of \textit{P. fenzlii} in Slovakia can be assigned to the community \textit{Boletum (aerei)–Russuletum luteotactae} (Śmarda 1972; Fellner 1988). This is typical for the thermophilous oak forests of Southern Europe and rarely present in extra-zonal sites in the Central Europe (Bujakiewicz 1992).

At all evaluated localities, \textit{Boletus aereus} was present, being a distinctive species of the aforementioned community (Śmarda 1972). Some of the other characteristic fungal species occurring at almost all evaluated localities of \textit{P. fenzlii} are \textit{Amanita caesarea}, \textit{Aureoboletus gentilis}, \textit{Boletus moravicus}, \textit{B. rhodoxanthus} and \textit{Leccinum crocipodium} (see Methods for data). We consider the co-occurring species \textit{Boletus appendiculatus}, \textit{B. impolitus}, \textit{B. regius} and \textit{Omphalotus olearius} to be further subcharacteristic species of this fungal community.

In general, knowledge of the species richness and distribution of fungi in Slovakia is deficient, far from complete, and varying strongly among regions (Adamčík et al. 2003). There are only a few works on the mycobiota of oak-dominated forests in Slovakia (Miháil 1995; Miháil 2006; Pavlík & Pavlíková 2006; Ripková et al. 2007). The fungal community at Končitý vrch hill has been classified as \textit{Boletus (aerei)–Russuletum luteotactae} (Kunca 2012). However, no fungal lists are available for many localities important to nature conservation. Such is the case of the Boky National Nature Reserve (NNR), one of the best-preserved old-growth oak forests, which is under almost no human impacts (Saniga et al. 2014). Only some species and records on dead wood were published from this locality (Vlasák 1989; Kotlava 1997). Miháil (pers. comm.) recorded \textit{Boletus aereus}, \textit{B. appendiculatus}, \textit{B. rhodoxanthus} and \textit{B. impolitus} there, which shows that the local fungal community is of a similar character to other Slovak sites of \textit{P. fenzlii}. For Másiarsky bok National Nature Reserve, where no relevant data were available for our research, only three \textit{Lactarius} species have been published (Caboň and Adamčík 2014). This locality was visited by the second author only twice. Some interesting lignicolous species were found (e.g. \textit{Buglossoporus quercinus}, \textit{Cerioporiopsis gilvescens}, \textit{Hericium cirrhatum}, \textit{Phellinus contiguus}), and no specific ectomycorrhizal ones. The reason for their low occurrence could be the rocky and scree terrain in this reserve.

\textbf{Concluding remarks}

In the Białowieża Virgin Forest, fungi typical for boreal old-growth coniferous forest (\textit{Amylocystis laponica}, \textit{Phellinus nigrolimitatus}, \textit{Phellinidium ferrugineofuscum}, Alfredsen et al. 2014; Karasiński & Wolkowycz 2015) encounter species preferring thermophilous oak forests, at least in Europe (e.g. \textit{Hapalopilus croceus}, Frature & Otto 2015; \textit{Spongipellis litschaueri}, \textit{Grifola frondosa}, Karasiński & Wolkowycz 2015). Thus, the find of \textit{Pluteus fenzliii} could represent either a remote site of its present occurrence or a remnant of its former distribution. Its occurrence at an isolated locality could be a consequence of global warming (Andrew et al. 2016). A similar case was documented for recent records of the Mediterranean fungus \textit{Gymnopilus suberis} in the region of thermophilous vegetation in the Czech Republic (Holec et al. 2016). On the other hand, \textit{Pluteus fenzliii} might be considered a relict of retreating continental oak forest in the Białowieża Virgin Forest. Continental oak woods were well represented in the past in Białowieża (Faliński 1986). In terms of site requirements they were similar to current stands of open thermophilous oak woods in southern Slovakia, where 11 localities of \textit{P. fenzlii} are known at present (Holec et al. 2018; this paper).

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