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Mycena laevigata (Fungi, *Agaricales*) in the heart of Central Europe – a prominent species of old-growth forests

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The distribution and ecology of *Mycena laevigata* was evaluated in the Czech Republic and Slovakia. We collected data on records from 32 Czech and 32 Slovak localities, mostly from dead wood of spruce, but also fir and rarely pine. *Mycena laevigata* is a distinctly submontane to supramontane species with its distribution peak in the montane zone and rare occurrence in the subalpine zone. Preferred habitats are supramontane spruce forests, submontane/montane mixed forests (beech, spruce, fir) and submontane beech/fir forests. Several extrazonal habitats are known, namely waterlogged spruce forests, bog forests and ravine forests. Records of *M. laevigata* clearly dominate in old-growth forests under protection, which are rich in dead wood of spruce and/or fir, while records from managed forests are extremely rare. The species is able to fructify on wood of all decay stages, but most frequently at advanced stages, from May to November, with peaks in June and September. The prevailing occurrence in old-growth forests shows that the species requires not only presence of dead conifer wood in any cold and humid environment, but also some degree of habitat continuity, i.e. minor human impact on the forest ecosystem. The species can therefore be used as a good indicator of habitat preservation. Its taxonomic identity was verified molecularly using the ITS sequence from Czechia. Sequences of Asian samples are somewhat different from the European ones. Its distribution in Europe is summarised and its ecology in other parts of Europe discussed.

Key words: *Basidiomycota*, distribution, ecology, naturalness, nature conservation, Czech Republic, Slovakia, ITS, taxonomy.

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Holec J., Dvořák D., Zíbarová L., Beran M., Zehnálek P., Peiger M., Kunca V. (2023): *Mycena laevigata* (Fungi, *Agaricales*) v srdci střední Evropy – význačný druh přirozených lesů. – Czech Mycol. 75(1): 35–52.

Rozšíření a ekologie druhu *Mycena laevigata* byla hodnocena v Česku a na Slovensku. Údaje o nálezech jsme shromáždili z 32 lokalit v Česku a 32 na Slovensku, převážně z mrtvého dřeva smrku, ale i jedle a vzácně borovice. *Mycena laevigata* je výrazně submontánní až supramontánní druh s převahou výskytu v horském stupni a vzácným výskytem v subalpínském stupni. Preferovanými biotopy jsou supramontánní smrkové lesy, submontánní/montánní smíšené lesy (buk, smrk, jedle) a submontánní jedlobučiny. Je známo i několik extrazonálních biotopů, zejména podmáčené smrčiny, rašelinné lesy a suťové lesy. Nálezy *M. laevigata* jednoznačně dominují v chráněných starých lesích bohatých na mrtvé dřevo smrku a/nebo jedle, zatímco nálezy z hospodářských lesů jsou extrémně vzácné. Druh je schopen tvořit plodnice na dřevě všech stadií tlení, ale nejčastěji se vyskytuje v pokročilých stadiích, od května do listopadu, s vrcholy v červnu a září. Převažující výskyt v přirozených lesích ukazuje, že druh vyžaduje nejen pouhou přítomnost mrtvého dřeva jehličnanů v jakémkoli chladném a vlhkém prostředí, ale také určitý stupeň kontinuity stanoviště spočívající v absenci většího vlivu člověka na lesní ekosystém. Druh lze tedy použít jako dobrý indikátor přirozenosti stanoviště. Jeho taxonomická identita byla ověřena molekulárně pomocí sekvence ITS z Česka. Sekvence asijských vzorků se od evropských poněkud liší. Je shrnuto rozšíření v Evropě a diskutována ekologie v jiných částech Evropy.

INTRODUCTION

Fungi preferring or restricted to old-growth forests are attracting more and more attention from mycologists and conservation ecologists (Heilmann-Clausen et al. 2017, Kunca et al. 2022), due to their rarity and threat resulting from the ever-shrinking area of such stands in all parts of the world. Some of them were even evaluated as bioindicators of such forests (e.g. Kotiranta et Niemelä 1996, Parmasto 2001, Holec 2003, Christensen et al. 2004, Blaschke et al. 2009, Halme et al. 2017). Lignicolous fungi predominate among them, especially perennial polypores, which are noticeable throughout the year in the form of conspicuous fruitbodies (Halme et al. 2009). Among bioindicators, gilled fungi (*Agaricales* s.l.) are represented by a smaller number of species (e.g. Blaschke et al. 2009). Their association with forest naturalness is not well known, as their fruitbodies are only recordable for part of the year depending on their fructification strategy (usually unknown) and the course of the weather.

Based on available published occurrence data (e.g. Kotlaba et Pouzar 1951, 1962, Kubička 1960, 1963, Svrček et Kubička 1964, Kuthan 1990, Holec et al. 2015, 2020, 2022, Holec et Kučera 2020) and our field experience from Czechia and Slovakia, we hypothesise that *Mycena laevigata* Gillet is a gilled fungus growing almost exclusively in old-growth forests. This is supported by results of an indicator analysis based on a field survey of permanent plots in various types of Czech forests (Dvořák et al. 2017), where *M. laevigata* is listed as a "faithful old-growth forest species". This lignicolous saprotroph lives on wood of conifers and is well

recognised by its subviscid whitish fruitbodies appearing in groups, slightly decurrent lamellae, greyish lower part of stipe, absence of a distinct smell, acuminate cheilocystidia, smooth hyphae of the pileipellis and diverticulate hyphae of the stipitipellis (Robich 2003, Aronsen et Læssøe 2016, our observations).

We decided to test the hypothesis that *Mycena laevigata* is associated with old-growth forests in Czechia and Slovakia by using all available occurrence data and comparing them with recently collected data on forest naturalness (www.naturalforests.cz for Czechia, https://pralesy.sk/lokality/ for Slovakia). Our goal was also to evaluate all other obtained data on the distribution and ecology of the species.

MATERIAL AND METHODS

Distribution and ecology data. Data used in this study were obtained from voucher specimens in the most important Czech and Slovak herbaria (BRA, BRNM, BRNU, CB, HR, MJ, OLM, PL, PRC, PRM), private herbaria (herb. LZ: L. Zíbarová, Ústí nad Labem; herb. HD: Helena Deckerová, Ostrava; herb. AL: A. Lepšová, Pěčín; herb. PVKU: V. Kunca, Zvolen; herb. TMKPVL: P. Tomka, Liptovský Mikuláš), published sources (see Introduction), the database of the Nature Conservation Agency of the Czech Republic (NDOP), available unpublished research reports and authors' research projects. These data sources cover both cultural and natural habitats. Acronyms of public herbaria are cited in accordance with Index Herbariorum (http://sweetgum.nybg.org/science/ih/). The identification of all voucher specimens was verified microscopically. Older collections from BRNM, OLM, PRC and PRM were revised by J. Holec and D. Dvořák. In Electronic Supplement 1, usually up to three records per locality are cited, mostly those documented by voucher specimens and simultaneously older, medium-aged and younger ones. However, more records are given if they provide details on substrate.

For the purpose of this paper, a locality is defined as a unique local geographical unit, e.g. mountain, valley, nature reserve, with a more or less homogeneous topography (same slope orientation etc.). From several localities, mostly the best-preserved and most intensively studied forest reserves (e.g. Boubínský prales), dozens of records are available (Electronic Supplement 2). For purpose of species distribution data, distribution map, habitat, naturalness and protection analyses, localities with multiple records are counted as one (however, records from different habitats or different elevations at the same locality are considered separately in habitat analysis). For the substrate analysis, each record was evaluated if not originating from the same wood unit or study plot in order to avoid pseudoduplications. Similarly, for the fructification analysis, multiple records from the same locality and day or week are counted as one.

The elevational zonation of Czechia and Slovakia is taken from Kotlaba (1984) as follows: up to 200 m (a.s.l.) – planar zone (lowland), 200–500 m – colline zone (hills country), 500–800 m – submontane zone, 800–1100 m – montane zone, 1100–1400 m – supramontane zone, 1400–1700 m – subalpine zone. In the case of multiple records from one locality covering two elevation zones or in the case of a borderline value, the location was classified according to its predominant character.

Wood decay stage is characterised according to the widely used five-level scale (Heilmann-Clausen 2001, Holec et al. 2015, 2020).

Missing information of some records was added secondarily by the authors from reliable sources, particularly elevation and approximate geographic location (www.mapy.cz), forest naturalness of Czech localities (https://naturalforests.cz/databank-localities) and Slovak localities

Fig. 1. *Mycena laevigata*, typical growth in dense rich groups. Šumava Mts, Boubínský prales, 11 Jun 2013. Photo J. Holec.

Fig. 2. *Mycena laevigata*, detail of fruitbodies. Šumava Mts, Spáleniště, 4 Sep 2018. Photo L. Zíbarová.

(https://pralesy.sk/lokality/, https://gis.nlcsk.org/islhp/mapa). All record data obtained are summarised in the Electronic Supplements 1, 2 which are the basic data sources in this paper. Geographic coordinates are not shown but can be provided on request from the corresponding author for purposes of serious research projects.

D N A s t u d y. For DNA amplification, direct PCR was carried out from one fresh specimen (Czech Republic, Lenora, Velká Niva, PRC 6386; for details, see Electronic Supplement 1) with a Phire Plant Direct PCR Master Mix (ThermoFisher, Czech Republic). A small piece of pileus trama was taken and put directly to reaction with primer set ITS1F, ITS4 (White et al. 1990). The amplification ran in Bento Lab (Bento Bioworks, London, UK) with standard PCR conditions for the ITS region. The obtained PCR product was sequenced from both directions with identical primers to those used for amplification at the Sequencing Laboratory of the OMICS Core Facility, BIOCEV (Vestec, Czech Republic). The generated sequence was edited in BioEdit (Hall 1999) and compared with 13 ITS sequences of *Mycena laevigata* available from the BOLD Systems database (NOBAS2801-16, NOBAS2840-16, NOBAS2841-16, NOBAS7143-19) and GenBank (JQ358808, MH930175, MK453048, MK733302, MK733303, MK733304, MW540695, OP508329, OQ025146) by aligning using MAFFT algorithms in the Geneious 7.1.9 software (Biomatters, Auckland, New Zealand).

RESULTS

DNA study

The one obtained sequence of the ITS region (GenBank OQ729827, from sample of Czech origin, see Methods) was of acceptable quality although of slightly shorter length (434 bp). The four Norwegian sequences from the BOLD Systems database were identical except for one substitution. Of the ten ITS sequences in GenBank annotated as *M. laevigata* one was indicated as unverified (JF908397) and not included in our analysis. Sequences from Fennoscandian samples (Finland, Norway) JQ358808 (100%) and MW540695 (99.77%) had the highest similarity to our sequence. Sequences MK733302, MK733303 and MK733304 of Chinese origin had a similarity of 98.39% (difference in two indels and five substitutions). Sequence OP508329 (eastern Russia) was identical in 97.7% positions (difference in four indels and six substitutions). Sequence MH930175 (Russia) was identical in 97.5% positions (difference in four indels and seven substitutions). Sequences MK453048 and OQ025146 from samples collected in China are highly different and certainly belong to another species.

Distribution

We collected data on records from 32 localities in Czechia and 32 in Slovakia (Fig. 3). Out of them, 27 were made in the 20th century (over 80 years starting from 1921) and 37 in the 21th century (over 22 years). In Czechia, most localities are concentrated in Bohemia (29), especially in the Šumava Mts (18) and several other mountain ranges (Krkonoše – 2, Novohradské hory – 2, Český les – 1, Brdy – 1).

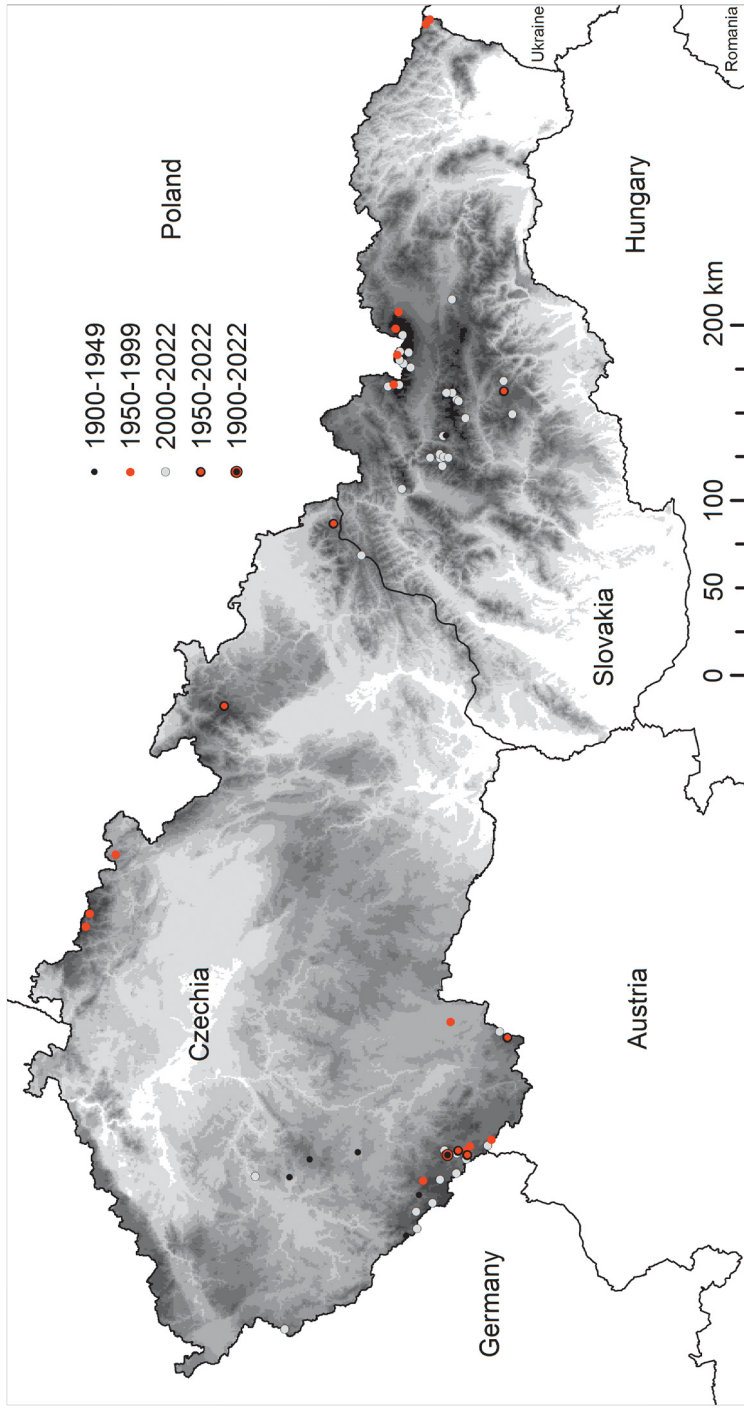

Fig. 3. *Mycena laevigata*, distribution in Czechia and Slovakia.

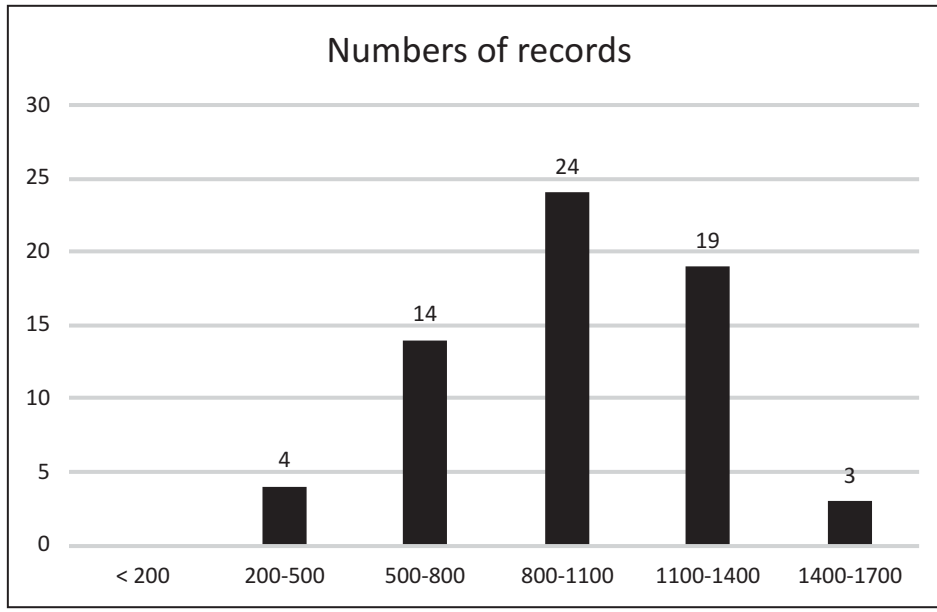

Fig. 4. Distribution of *Mycena laevigata* records over elevational zones (m a.s.l.).

In Moravia there are only 3 localities, all of them from mountains (Moravskoslezské Beskydy, Hrubý Jeseník). In Slovakia, localities are situated in most major mountain ranges, particularly Západné Tatry (8), Nízke Tatry (7), Veľká Fatra (6) and Vysoké Tatry (3), but also in Belianske Tatry, Poľana, Veporské vrchy and Bukovské vrchy.

Numbers of localities in individual elevational zones are shown in Fig. 4. There are no localities from the lowlands and only a few from hills, all of them from Czechia (the lowest situated record is from an elevation of 325–350 m). Most localities are in the montane and supramontane zones, and three even in the subalpine zone (Slovakia only: maximum 1535 m a.s.l., Ďumbier virgin forest, Nízke Tatry Mts).

Habitats

The habitat description of most records (Electronic Supplement 1) is too brief for a detailed analysis at the level of exact vegetation units. In most cases, only dominant tree species are reported. Out of 83 records with such data (pseudo-duplications removed, see Methods), most ones are from pure *Picea abies* forests, either in the supramontane zone (see above) or in stream valleys of the montane zone (Fig. 5). Another widely represented habitat is the typical and widely

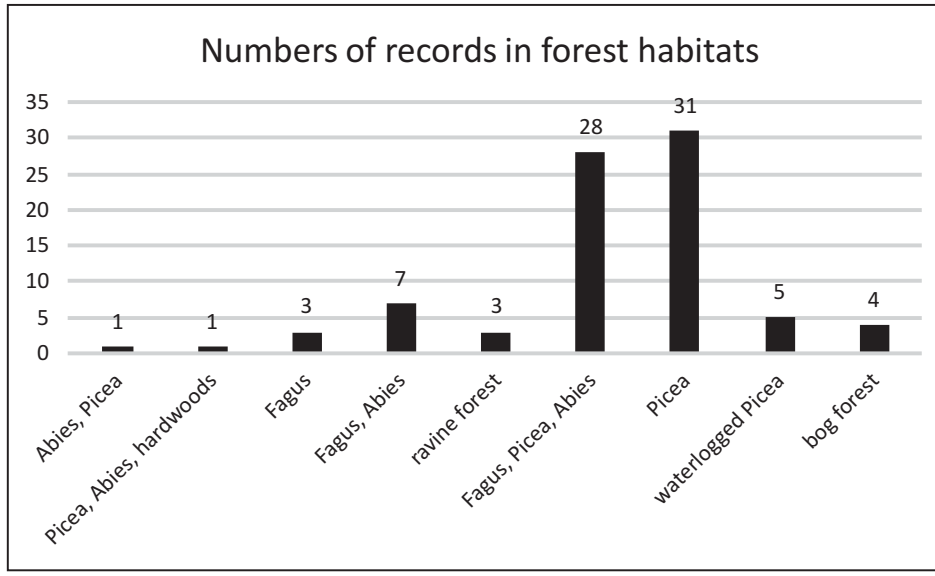

Fig. 5. Records of *Mycena laevigata* in various forest habitats. Tree dominants are given, if not, tree composition is as follows: ravine forest – *Acer*, *Ulmus*, *Fagus*, *Picea*, *Abies*; bog forest – *Pinus sylvestris*, *Picea*, *Betula*.

distributed Central-European montane (less frequently supramontane) mixed forest, composed of *Fagus sylvatica* with admixed *Picea abies* and *Abies alba*. On steep bouldery to rocky slopes, these forests often pass into ravine forests, an another habitat recorded for *M. laevigata*. Other forest types are less represented. Waterlogged *Picea* forests are mostly situated along streams or around peatbogs which also applies to bog forests composed of *Pinus sylvestris*, *Picea* and *Betula*. In submontane (rarely montane) *Fagus-Abies* and almost pure *Fagus* forest, *Mycena laevigata* mostly grows on wood of *Abies alba*. In the case of 4 records from the hills (Fig. 4), their habitat is unknown with the exception of the record at the lowest elevation (Chlumská stráň Nature Reserve), which is from a mostly even-aged coniferous forest with dominance of *Abies alba* and admixture of *Picea abies*, on a steep WNW slope of the incised valley of a stream flowing into the wide valley of the Berounka river.

Habitat naturalness and protection

Data on forest naturalness are available for 53 of 64 Czech and Slovak localities of *M. laevigata* (Electronic Supplement 1). As shown in Fig. 6, most localities (47, i.e. 89%) belong to old-growth forests (virgin, natural, near-natural) and only 6 are man-influenced. The protection (= nature conservation) status of localities

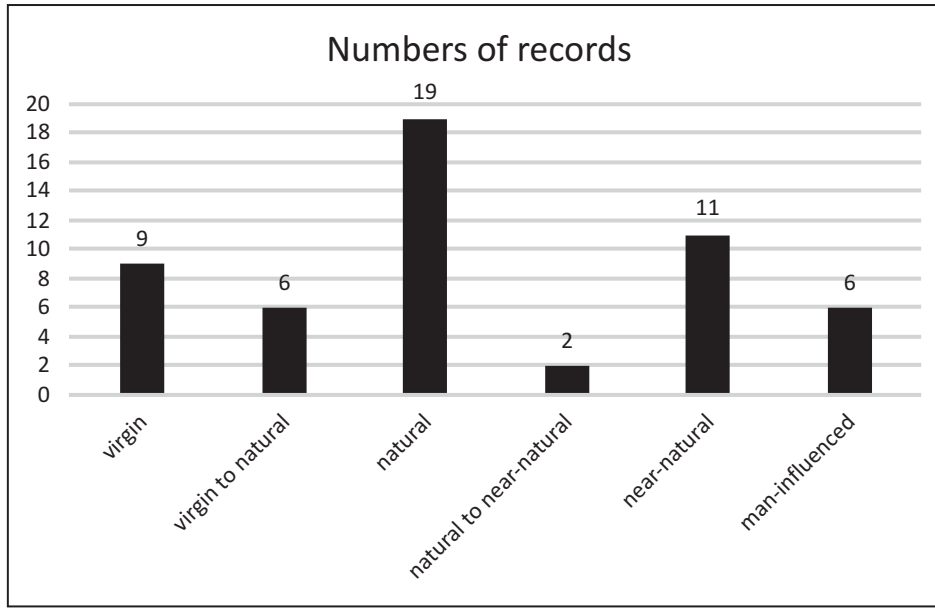

Fig. 6. Forest naturalness at Czech and Slovak localities of *Mycena laevigata*.

(data status as of 2022) is known for all 64 localities (Fig. 7). Only two of them are situated in an "ordinary unprotected landscape" (i.e. man-influenced or man-made) and two are under the least strict form of protection (protected landscape area - PLA). Sixty localities are under a strict form of protection, being either small-scale reserves (nature reserve or national nature reserve), or in large-scale ones (national park – NP). The prevailing category (30 localities) is represented by small strictly protected sites (national nature reserve or natural zone of NP) located in a large-scale protected area (national park).

Substrate

Most of the 93 records with a substrate given (Electronic Supplement 1) come from *Picea abies* wood (71, i.e. 76%). Another frequent substrate is *Abies alba* (14, i.e. 15%). Conifer, either *Picea* or *Abies*, is given as substrate seven times. There is also one reliable record from wood of *Pinus sylvestris* (near Blatná, leg. K. Cejp). There are no records from wood of broadleaved trees.

The most frequent substrate types are fallen trunks (77 of 92 specified records, i.e. 84%), often covered with mosses, followed by stumps (12 records, i.e. 13%). There are also single records from a branch, a root in soil, and a trunk cavity.

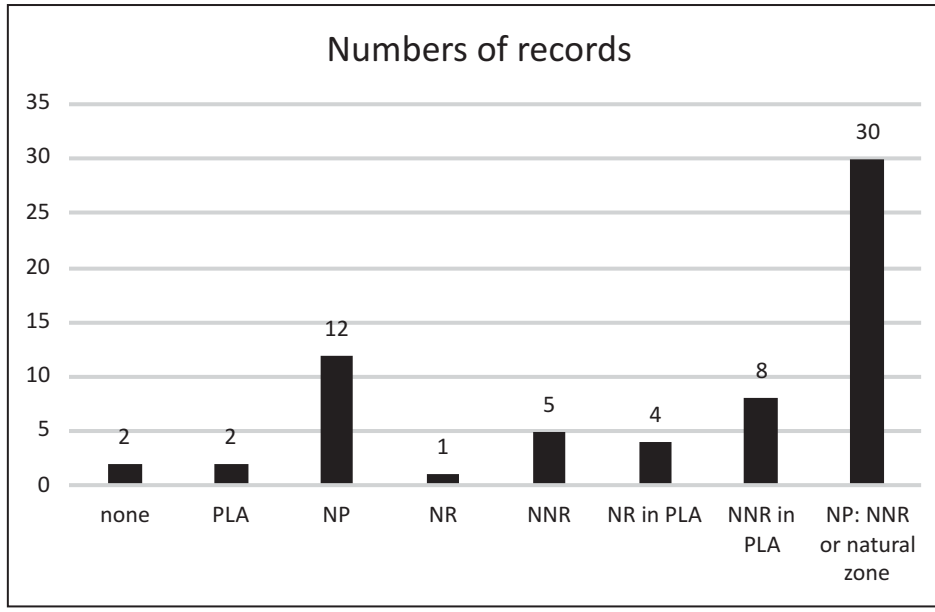

Fig. 7. Nature conservation status of the Czech and Slovak localities of *Mycena laevigata*. NP: national park, NNR: national nature reserve, NR: nature reserve, PLA: protected landscape area. Categories cited as NR and NNR represent small-scale reserves located outside large-scale ones.

Out of the 33 records with a wood decay stage given (Electronic Supplement 1), 26 (79%) are from medium to advanced stages (3–4), but there are also 4 records from both initial stages (1–2) and 3 from the final stage (5). Detailed information from the Boubínský prales virgin forest in the Šumava Mts (Electronic Supplement 2), the richest locality known, shows a similar distribution of records along the decay scale and the proportion of *Picea*/*Abies*/conifer records.

Fructification

After removing pseudoduplications (see Methods), we could use fructification data for 86 records (Electronic Supplement 1). They cover the period from early May to late October. There are two fructification peaks: June and September (Fig. 8). Detailed information from the Boubínský prales virgin forest in the Šumava Mts (Electronic Supplement 2) showed the same fructification peaks and added several records from November (the latest was November 25).

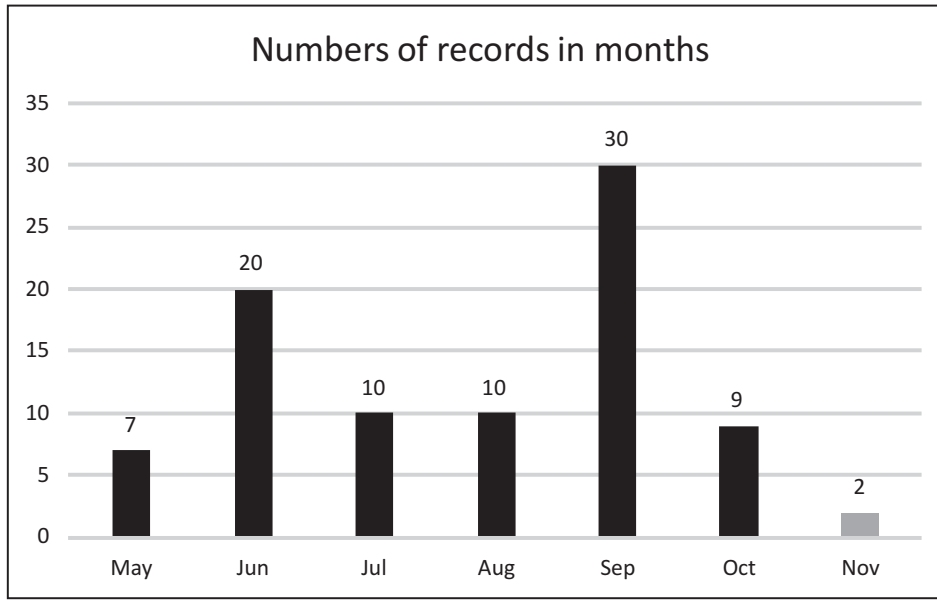

Fig. 8. Distribution of *Mycena laevigata* records over the season. Data for black columns are based on Electronic Supplement 1, for the grey column on Electronic Supplement 2.

DISCUSSION

DNA study

Comparison of our ITS sequence from a sample of Czech origin with sequences labelled *M. laevigata* in GenBank and in the BOLD Systems database showed clear conspecificity with those of Fennoscandian origin. The sequences of samples from central and eastern Asia are still relatively similar (more than 97%) but indicate existence of vicariant populations or even a different species. In view of the fact that *M. laevigata* was described from Europe (France; see Gillet, Hyménomycètes (Alençon): 274, 1878, '1876'), this name should be retained for the European population. Broader geographical sampling and more genes will be necessary to solve the taxonomy of *M. laevigata* in Eurasia.

Distribution, ecology, nature conservation

The relatively large number of localities of *M. laevigata* in Czechia (32) and Slovakia (32) could give the impression that the species is widely distributed. However, the real situation is more complicated. The species is completely absent in some areas (e.g. central and southern Moravia, southern Slovakia), while it is more common or even abundant at suitable localities in other areas. It is

completely absent in the lowlands and very rare in the hills. There is only one recent record from the latter elevational zone (Chlumská stráň), located at a site with a relatively cold microclimate (shady slope of a stream valley). The other two records (Boreček, Blatná) are already historic (1926, 1929) and difficult to interpret in terms of forest naturalness at the time of collection. Current occurrence of the species at its former sites is highly improbable both from the viewpoint of ongoing climatic change (warming) and possible habitat change (the sites are not protected). It is worth noting that there are no records at microclimatically suitable localities in inverse spruce forests at the bottom of sandstone gorges in the Bohemian Switzerland NP (elevation ±200 m), where other boreo-montane species grow (Holec et Wild 2011). On the other hand, *M. laevigata* was found in Adršpašské skály rocks (1950) having similar habitats. However, this site has a much higher elevation and is therefore microclimatically more suitable.

We can summarise that *M. laevigata* is a distinctly submontane to supramontane species with its distribution peak in the montane zone and rare occurrence in the subalpine zone (Slovakia only). This characteristic is closely related to the preferred habitats, which are predominantly supramontane spruce forests, submontane/montane mixed forests (beech, spruce, fir) and submontane beech/fir forests. In addition, several extrazonal habitats are known, namely waterlogged spruce forests, bog forests and ravine forests.

Records of *M. laevigata* clearly dominate in old-growth forests under protection, which are rich in dead wood of spruce and/or fir. Records from managed forests are extremely rare even though all generations of Czech and Slovak mycologists (including the authors) have visited them with an intensity comparable to old-growth forests. If the fungus grew there, they would certainly document it because it is a conspicuous rarity. The species is able to fructify on wood of all decay stages, but is most frequent at advanced stages 3 and 4, from May to November, with peaks in June and September. At the richest localities like the nature reserves of Boubínský prales and Žofínský prales, it forms a typical early summer aspect of large groups of fruitbodies on dozens of wood units, mostly fallen trunks and naturally formed stumps. Such forest reserves seem to represent refugia where the species has ideal conditions and apparently spreads from trunk to trunk. Other localities in the Czech Republic, e.g. Milešický prales, Velká Niva, Malá Niva, Spáleniště, Medvědice (all in Šumava Mts, NP) and Bílá Opava (Jeseníky, PLA) show repeated records of the species. In Slovakia, comparable localities are e.g. Jánošíkova kolkáreň, Kundračka, Skalná Alpa (Veľká Fatra Mts, NP) and Dobročský prales (Veporské vrchy Mts). A higher number of records is also known from nature reserves in the Západné Tatry, Vysoké Tatry, Nízke Tatry and Bukovské vrchy Mts, all situated in national parks. This fact nicely documents that such a 'double-scale' protection supports the occurrence of *M. laevi-*

gata in the landscape. Large-scale protected areas (PLA, NP; see Fig. 7), where nature should take precedence over economic interests, form good basis for nature reserves (dozens to hundreds of hectares) exempted from commercial forestry interventions. As a whole, PLAs and NPs are suitable sub-areas where the species can survive at several locations. Good examples are the Šumava Mts and mountains in the Liptov region (Západné Tatry, Vysoké Tatry, Nízke Tatry), where the more frequent occurrence of *M. laevigata* may be supported by the supply of spores from refugia in nature reserves. On the other hand, a rich relict locality like Žofínský prales (Novohradské hory Mts, unprotected as a whole) does not seem to be able to support creation of new localities since its vicinity is almost exclusively covered by younger man-made or man-influenced spruce monocultures with hardly any coarse wood debris.

The importance of habitat continuity consisting in the presence of large decaying wood units (remnants of the 'olden days') is represented e.g. by the locality of Olšinka in the Šumava Mts (moreover, a region rich in *M. laevigata* sites and thus also spores). The site is currently afforested by younger man-influenced spruce forest but the fungus was found there on old decaying stump from the past forest generation. It shows that forest continuity can be disrupted suddenly by cutting but the survival of such a lignicolous fungus can be ensured by old wood units left (but probably only for a certain time, since they disappear by decomposition).

The prevailing occurrence of *M. laevigata* in old-growth forests with long continuity, apparent failure to spread from such refugia to neighbouring managed forests, and richer occurrence in regions with better preserved landscape (protected landscape areas and above all national parks) suggests that the species requires not only the mere occurrence of dead conifer wood in a cold and humid environment, but also some degree of habitat continuity consisting in absence of major human impact to the forest ecosystem (especially large-scale cutting and wood removal).

Data not included in the analysis and map

A collection identified as *M. laevigata* from a site called Močidla in Obora forest near Moravské Knínice (8 Oct 1948 leg. et det. F. Šmarda, BRNM 327004) was revised by D. Dvořák (Jan 2023). It represents another species, since the cheilocystidia are covered by richly branched outgrowths of the *M. maculata* type.

A collection from the Hrubovodské sutě Nature Reserve in the Oderské vrchy hills (29 Sep 2004 leg. et det. M. Pejchar, OLM Bf2015) was revised by J. Holec (Jan 2023). It clearly represents *Mycena zephirus*, which agrees with the substrate given on the label: wood remnants and needles of *Picea abies*.

A collection from Mnichovice in Central Bohemia (18 Jul 1948 leg. et det. V. Vacek, PRM 713357) was revised by J. Holec (Jan 2023). The substrate is a branch of a deciduous tree. The fungus resembles *M. laevigata* macroscopically but the substrate and occurrence in this warm part of Czechia make the identification unlikely. Moreover, the cheilocystidia are not acute but have an obtuse apex. It could represent a pale form of *M. niveipes*, another species of sect. *Fragilipedes* with microcharacters similar to *M. laevigata* but growing on deciduous wood.

The record from Polom Nature Reserve (Jankovský et al. 2004) is highly improbable due to the substrate given (*Alnus glutinosa*, fungus growing as saprophyte on the ground). Moreover, L. Zíbarová did not find *M. laevigata* there during her visits (Tejklová et Zíbarová 2019).

Comparison with available data from nearby countries

There are 37 entries of *M. laevigata* in the German database (DGfM on-line). Most of them are from Bavaria, i.e. the region neighbouring Czechia, namely from the Bohemian Forest (= Bavarian Forest, Šumava Mts), the Alps and their foothills. Other localities at higher elevations are in the Schwäbische Alb and Sauerland. However, several records are also from lowlands in northern Germany, which are hardly comparable with most of the Czech and Slovak ones, especially when we do not have detailed information about them. Misidentifications cannot be excluded.

In Austria, 64 records are databased (Austrian Mycological Society on-line). Their distribution pattern resembles the Czech and Slovak ones: no records in lowlands, isolated records in the hills, and the vast majority in the Alps and their foothills plus the montane Waldviertel region neighbouring Czechia, namely localities in the Novohradské hory Mts. The elevational maximum of the species is higher than in Slovakia (1500–2000 m a.s.l.). The following information was kindly provided by an Austrian reviewer: *Larix* is given as substrate for one collection. A record from the lowlands (Burgenland) is possibly misidentified. Another one from *Fagus* in the Grazer Bergland is also uncertain. In two finds with the substrate indication *Fagus*, the substrate is almost certainly misidentified, since also old lying conifers occur at both localities.

The Swiss database (SwissFungi on-line) shows 48 records in the elevational range 400–2390 m with their peak at 1000–1600 m. Records are from May to December, with a peak in June and July. The species is found in a range of habitats similar to those in our study. In addition to the tree species known as substrate from Czechia and Slovakia (*Picea*, *Abies*, rarely *Pinus sylvestris*), one record is reported from wood of *Larix*.

In Poland, *M. laevigata* is particularly known from two national parks (Babia Góra, Białowieża) and the Puszcza Augustowska primeval forest (Wojewoda 2003). These localities have a similar level of naturalness and nature protection to the Czech and Slovak ones. Reported occurrence on hardwoods (Wojewoda 2003) is highly improbable with respect to the substrate preference of the species.

In Ukraine, there is an old published record from the Eastern Carpathians (Pilát 1940: Svidovets range). Due to the favourable conditions in this part of the Carpathians, comparable to the neighbouring Carpathian mountains of Slovakia, we believe that the species will have more localities there.

We found no published data on occurrence of *M. laevigata* in Hungary, a country neighbouring Slovakia. This is quite understandable seen the lack of suitable habitats (no high mountain ranges, warm climate, low representation of spruce and fir). The absence of the species was confirmed by Bálint Dima (Budapest) and his colleagues interested in *Mycena* (pers. comm., 7 Feb 2023).

It can be summarised that in the mentioned regions of Central Europe the species has a similar ecology in terms of preference for elevation and habitats. Unfortunately, data on naturalness are not available in public databases so that a comparison with our data was possible only for Poland.

Notes on European distribution

Mycena laevigata is widely distributed in Northern Europe, namely in the hemiboreal and especially boreal zone of Norway, Sweden and Finland (Knudsen et Vesterholt 2012) and in the Baltic countries (www.gbif.org). Based on data from Norway (https://samlingsportal.nhm.uio.no/museum/nhm), *Pinus* is a far more common substrate than in Central Europe. The fungus is not known from Denmark or the United Kingdom (Aronsen et Læssøe 2016). The last mentioned authors consider records from the Netherlands unusual and deserving revision, which is an opinion we share. Records from Central Europe and Ukraine are summarised in the previous sections. In the Alps, except for Switzerland, Germany and Austria (see above), the species is further known from Italy (Robich 2003) and France (www.gbif.org). There are also single records from the Spanish Pyrenees (Olariaga Ibarguren on-line) and the Rila Mts in Bulgaria (Kuthan et Kotlaba 1988).

Aronsen et Læssøe (2016) characterise the species as “mainly hemiboreal-boreal-subalpine”. Based on the data summarised here, we specify that the species prefers the hemiboreal to boreal zone of Northern Europe and the mountains of Western, Central, Eastern and Southern Europe, where it occurs mainly from the submontane to subalpine zone with a peak in montane beech-spruce-fir forests and supramontane spruce forests (elevations 800–1600 m a.s.l.). More generally it can be characterised as a prominent boreal-montane element.

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