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Ecology and distribution of *Kneiffiella curvispora* (Hymenochaetales, Basidiomycota) in Central Europe and its phylogenetic placement

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With 8 figures and 2 tables

Abstract: Numerous recent data on occurrence, substrates, and habitats of the rare saproxylic corticioid fungal species, *Kneiffiella curvispora*, were collected in order to describe its ecological demands in detail. Based on our records, the species prefers medium to strongly decayed, several decades dead, large trunks of *Abies alba* (less frequently also *Picea abies*) situated in mixed (sub)montane old-growth forests in which *Fagus sylvatica* dominates and there is sufficient host substrate at altitudes of 500–1220 m and avoids man-influenced forest habitats. Shady and slowly drying places on trunks with strongly decayed wood (cavities, undersides) are favoured types of microhabitat. Fungal (several times also bryophyte and lichen) communities on trunks inhabited by *K. curvispora* are described with emphasis on co-occurring species of conservation value. In total, 167 species were identified on 30 trunks with presence of *K. curvispora*. A total of 23 species are red-listed. Generally common species (*Calocera viscosa*, *Lactarius subdulcis*, *Mycena stipata*, *Galerina hypnorum* and *Physisporinus sanguinolentus*) were the most frequent on the occupied trunks. No evidence was found that *K. curvispora* requires a prior presence of other fungal species in the succession process on decaying trunks. The distribution of the species in Central Europe is summarized. The first collection from Slovakia is presented as well as several new localities of the species in the Czech Republic. The gradual decline of fir (and spruce) in favour of the spreading beech represents the most serious long-term threat to the species populations. The first phylogenetic tree containing complete ITS was calculated to show the placement of *K. curvispora* in the current phylogenetic tree of *Kneiffiella*.

Key words: *Hyphodontia* s.l.; rare species; taxonomy; *Abies alba*; *Picea abies*; microhabitats; old-growth forests; Czech Republic

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Introduction

Kneiffiella curvispora (J. Erikss. & Hjortstam) Jülich & Stalpers is a remarkable corticioid fungal species described in 1969 and formerly classified in the genera *Hyphodontia* J. Erikss., *Chaetoporellus* Bondartsev & Singer ex Singer, and *Grandinia* Fr. (Eriksson & Hjortstam 1969, Eriksson & Ryvarden 1976, Jülich 1982). It differs from other *Kneiffiella* species by thin-walled tramacystidia and very small and strongly curved basidiospores (Jülich & Stalpers 1980, Riebesehl & Langer 2017).

In Europe, *K. curvispora* is considered a boreo-montane species, growing on decaying trunks of coniferous trees (*Picea abies*, *Pinus sylvestris*, *Abies alba*) (Langer 1994, Eriksson & Ryvarden 1976, Hjortstam 1973, Krieglsteiner 1989, Dämon 2000, Kunttu et al. 2011, Kunttu et al. 2015, Kunttu et al. 2019), with only exceptional records on broadleaved trees (*Betula*, *Populus tremula*) from Finland (Kunttu et al. 2011, Kunttu et al. 2019).

Although well known (but still not common) from Fennoscandia (Eriksson & Hjortstam 1969, Hjortstam 1973, Kunttu et al. 2011, Kunttu et al. 2015, Kunttu et al. 2019), where *K. curvispora* is reported from different types of boreal forests, the species is only sporadically collected in several countries of Central and (South-)Eastern Europe, namely Austria (Dämon 2000, Dämon & Krisai-Greilhuber 2017), Czech Republic (Holec et al. 2015a, Holec et al. 2020, Holec & Kučera 2020), Germany (Grosse-Brauckmann 1990), Poland (Langer 1994, Karasiński et al. 2009, Gierczyk et al. 2019), Romania (Hallenberg & Toma 1987), Russia (Ghobad-Nejhad et al. 2009) and North Macedonia (Karadelev et al. 2018). Bernicchia & Gorjón (2010) also mention the species from Estonia, Croatia, Italy and Switzerland, but these data are based on unpublished datasets and should be verified in the future.

In this article, we summarize the current knowledge of the distribution of *K. curvispora* in Central Europe and amend these data by our recent records from the Czech Republic and Slovakia. We describe its ecological demands in detail, based on our finds and draw attention to the conservation value of this formerly neglected species. In addition, internal transcribed spacer (ITS) sequences were generated and the first phylogenetic tree for complete ITS with *K. curvispora* was calculated to show its placement in the current phylogenetic tree of *Kneiffiella*.

Methods

Field work

Field data were obtained mostly as part of our work on two large-scale projects (EHP-CZ02-OV-1-021-2014, 0113/17/900 (MŽP 170368) dealing with the monitoring of lignicolous fungi and other groups of organisms in the best preserved old-growth forest nature reserves throughout the Czech Republic.

During the years 2015–2020, trunks selected from the 100 thickest ones of *Picea abies* (Boubínský prales) and *Abies alba* (Salajka, Mionší, Boubínský prales, Žofínský prales) were inspected four times during one (or up to three) seasons at each locality (for exact years of monitoring and number of field inspections at each locality, see Table 1 in the electronic supplement). The number of investigated trunks varied between 30 (*Abies alba* in the Boubínský prales) up to 58 (*Abies alba* in the Žofínský prales). Occurrences of fruitbodies and stromata of all groups of macroscopic fungi visible with the naked eye (about 2 mm in size and larger) were recorded. In the case of Žofínský prales, corticioid fungi and resupinate heterobasidiomycetes are still under identification and were not included into the dataset for this reason. Microhabitat characteristics, namely position on the trunk (upper side, lateral side, underside, cavity, snag, lower/crown part, branches, etc.), wood decay degree (see below) and presence/absence of bark and mosses in the place of growth of the fruitbody were cumulatively recorded for each species during each visit in order to specify their ecological demands. For a more detailed view of the way of selection of the trunks and other methods of field work in the years 2015 to 2020, see Holec et al. (2020) and Holec & Kučera (2020). For segments of the Boubínský prales virgin forest, see Holec et al. (2015a: 163, 165).

Some data from the years 2019 and 2020 (part of data from Boubínský prales and Salajka) were obtained as part of mycological monitoring of permanent circular plots 500 square metres large, for which all macroscopic lignicolous fungi were recorded on selected rotting wood objects during one autumnal mycological inspection. In general, this methodology is based on the work by Bässler et al. (2010).

A few records come from standard field trips or extensive surveys (some records from Boubínský prales, Diana and Slovakia). In these cases we do not have many detailed data on the substrate and species composition of the communities on the trunks.

Wood decay stages were estimated in accordance with Heilmann-Clausen (2001) and Holec et al. (2015a) as follows: (1) wood hard, almost impossible to penetrate with a knifepoint; (2) wood slightly softened, knifepoint penetrates at most a few millimetres; (3) wood soft, knife penetrates several centimetres, the wood can be pressed with fingers and larger wood parts can be removed with a knife; (4) wood very soft, knife penetrates several centimetres and wood parts can be separated with fingers; (5) wood in the form of mash, original trunk shape no more visible.

Morphological identification

The morphological identification of fungi was based on dried specimens, deposited in PRM and CB (acronyms follow Index Herbariorum http://sweetgum.nybg.org/science/ih), and in the first author's personal herbarium (JB). Microscopic preparations were made in Melzer's reagent, lactophenol – cotton blue solution and in 5% Congo red – NH_3 or KOH solution. Identification keys and descriptions in reputable monographs (Eriksson & Ryvarden 1976, Langer 1994, Bernicchia & Gorjón 2010) as well as in modern taxonomical studies (Yurchenko & Wu 2016, Riebesehl & Langer 2017) were used for identification.

Molecular study

DNA was extracted with the E.Z.N.A.® Fungal DNA Mini Kit (Omega Bio-Tek, VWR, Radnor, Pennsylvania, USA). Different combinations of the following primers were used to amplify the ribosomal DNA marker ITS (including ITS1, 2 and 5.8S gene): ITS1-F (Gardes & Bruns 1993), ITS1, ITS2, ITS3 and ITS4 (White et al. 1990). PCR products were purified with DNA Clean & Concentrator™ - 5 (Zymo Research, Irvine, California, USA). The DNA sequencing was implemented by LGC Genomics GmbH (Berlin, Germany).

Newly generated DNA sequences were edited with MEGA7 (Kumar et al. 2016) under consideration of the five-guideline quality check (Nilsson et al. 2012) and deposited in NCBI GenBank (Benson et al. 2018; Table 1). NCBI GenBank (https://ncbi.nlm.nih.gov) and the UNITE database (https://unite.ut.ee; Nilsson et al. 2019) served as sources for other DNA sequences used in this study. Two representatives of the other genera of *Hyphodontia* s.l. were included in the dataset as well as *Skeletocutis odora* (Polyporales) as the outgroup for the phylogenetic calculation. The alignment was performed with MAFFT v.7 online (Katoh & Standley 2013), using the L-INS-i strategy. Maximum Likelihood (ML) was used for the subsequent phylogenetic analysis. The calculation of the DNA substitution model and ML analysis was carried out with MEGA7. For both calculations, a partial deletion of gaps with 95% site coverage cut-off was used, together with other settings as default. The bootstrap (BS) method was selected for a test of phylogeny with 1000 replications. MEGA7 was used for processing the phylograms, and GIMP 2.10.18 (http://gimp.org) for the final editing.

Abbreviations used in the text: DBH – diameter at breast height; not. – „notavit" (recorded without preservation of a herbarium specimen; see Kotlaba 1999); (N)NR – (National) Nature Reserve; RILOG – Research Institute for Landscape and Ornamental Gardening; ID – identification number.

Results and discussion

Taxonomy

Kneiffiella curvispora (J. Erikss. & Hjortstam) Jülich & Stalpers (Fig. 1a–d)

≡ *Hyphodontia curvispora* J. Erikss. & Hjortstam

≡ *Chaetoporellus curvisporus* (J. Erikss. & Hjortstam) J. Erikss. & Hjortstam

≡ *Grandinia curvispora* (J. Erikss. & Hjortstam) Jülich

Description based on our collections

Basidiomata often large (up to several dm^2), strictly resupinate, adnate, whitish, cream-coloured to pale ochraceous when old. Hymenophore odontioid, aculei up to 3 mm long, cylindrical to conical, often arranged densely in parallel rows on strongly decayed wood with some projecting hyphae at apices (lens!). Subiculum thin, concolorous with aculei. Margin indistinct, without rhizomorphs.

Hyphal system monomitic, hyphae thin-walled to distinctly thick-walled in subiculum, 3–4 µm in diameter, clamped at all septa. Cystidia growing from subhymenium, thin-walled, cylindrical to fusiform, without encrustation, apically obtuse, ca 40–80 × 4–7 µm. Basidia clavate to subcylindrical, slightly constricted in middle part, with 4 sterigmata, 10–15 × 4–5 µm, basally clamped. Spores narrowly allantoid, strongly curved, thin-walled, smooth, negative in Melzer's reagent, 4–5 × 1–1.5(–2) µm. For a more detailed description, see Langer 1994, Eriksson & Ryvarden 1976 and Dämon 2000.

With some experience and when typically developed and mature, *K. curvispora* may be identified or at least purposefully searched for already in the field, as its creamy, often large basidiomata are strikingly odontioid and grow on strongly decayed coniferous wood. Microscopic confirmation is easy for the combination of thin-walled leptocystidia and strongly curved, very small and narrow spores, which is unique among macroscopically similar species. *Kneiffiella alutacea* (Fr.) Jülich & Stalpers (Fig. 1e) also has thin-walled tramal cystidia, but differs by smaller aculei and somewhat longer, only slightly curved spores. Other odontioid *Hyphodontia* s.l. species have ellipsoid or cylindrical spores and/or different cystidia. The microscopically very similar *Kneiffiella abdita* Riebesehl & E. Langer (= *Chaetoporellus latitans* (Bourdot & Galzin) Bondartsev & Singer ex Singer) differs by its labyrinthine poroid to irpicoid hymenophore and somewhat smaller spores and basidia, and based on our experience it is a rare species growing on hardwood trees in floodplain and beech forests (Dvořák & Běťák 2017, Tejklová & Zíbarová 2018).

Collections studied

Czech Republic

Český les Mts., Rozvadov, Diana NR, near-natural beech-spruce forest, 500–530 m a.s.l., on strongly decayed wood of coniferous tree, 16 Jul. 2017 leg. J. Kelnerová, det. J. Kout, rev. J. Běťák (JB17/306), dupl. in herbarium of the University of West Bohemia.

Šumava Mts. (= Bohemian Forest), near the village of Zátoň, Boubínský prales NNR, fenced core area: segment BP1g (Holec et al. 2015a), montane virgin forest (*Picea abies*, *Fagus sylvatica*, *Abies alba*), 1010–1100 m a.s.l., on fallen trunk of *Picea abies*, decay stage 4, DBH 35 cm, 26 Aug. 2013 leg. J. Běťák, det. J. Běťák (JB 13/771); ibid., segment BP1g, 1065 m a.s.l., on fallen trunk of *Picea abies* (RILOG ID 110557), decay stage 3,

Table 1. Specimens included in the phylogenetic study. Newly generated sequences are shown in bold.

Species	Specimen voucher	GenBank or UNITE accession number	Reference	Country
Fasciodontia brasiliensis Yurchenko & Riebesehl	MSK-F 7245a, Holotype	MK575201	Yurchenko et al. 2020	Brazil
F. bugellensis (Ces.) Yurchenko, Riebesehl & Langer	KAS-FD 10705a	MK575203	Yurchenko et al. 2020	France
Hastodontia hastata (Litsch.) Hjortstam & Ryvarden	KHL 14646 (GB)	MH638232	Viner et al. 2018	Norway
H. halonata (J. Erikss. & Hjortstam) Hjortstam & Ryvarden	HHB-17058 (CFMR)	MK575207	Yurchenko et al. 2020	Mexico
Hyphodontia borbonica Riebesehl, Langer & Barniske	FR-0219441, Holotype	KR349240	Riebesehl et al. 2015	Réunion
H. pallidula (Bres.) J. Erikss.	UC 2022820	KP814340	Rosenthal et al. 2017	USA, Oregon
Kneiffiella abieticola (Bourdot & Galzin) Jülich & Stalpers	KHL 12498 (GB)	DQ873601	Larsson et al. 2006	Sweden
K. alienata (S. Lundell) Jülich & Stalpers	CBS 127219	MH864327	Vu et al. 2019	USA, North Carolina
K. alutacea (Fr.) Jülich & Stalpers	KAS-GEL 2284	DQ340340	Yurchenko et al. 2020	Germany
K. barba-jovis (Bull.) P.Karst.	KHL 11730 (GB)	DQ873609	Larsson et al. 2006	Sweden
K. cineracea (Bourdot & Galzin) Jülich & Stalpers	KAS-GEL 4958	DQ340336	Yurchenko et al. 2020	Réunion
K. curvispora (J. Erikss. & Hjortstam) Jülich & Stalpers	O-F-248048	UDB038099	unpublished	Norway
	PRM 935571	**MW345629**	**this study**	**Czech Republic**
	PRM 954540	**MW345630**	**this study**	**Slovakia**
K. decorticans (Gresl. & Rajchenb.) Hjortstam & Ryvarden	SP 415980	KY081795	Riebesehl & Langer 2017	Argentina

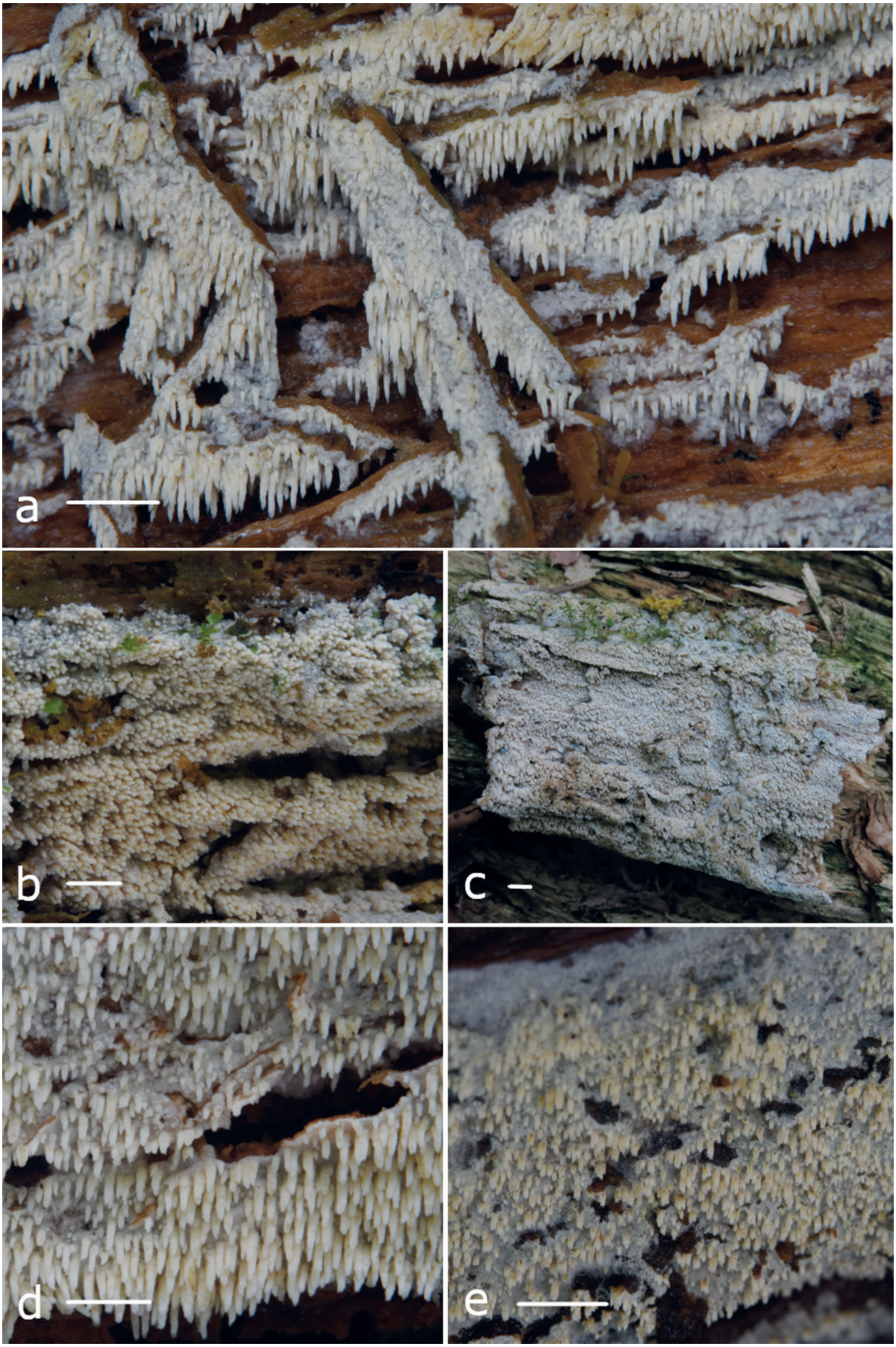
Table 1. cont.

Species	Specimen voucher	GenBank or UNITE accession number	Reference	Country
K. efibulata (J. Erikss. & Hjortstam) Jülich & Stalpers	GB-0151167, Holotype	KY081796	Riebesehl & Langer 2017	Sweden
K. floccosa (Bourdot & Galzin) Jülich & Stalpers	UC 2022902	KP814441	Rosenthal et al. 2017	USA, Minnesota
K. palmae Rick ex Hjortstam & Ryvarden	FR 7	KP689185	Wang et al. 2016	China
K. pilaecystidiata (S. Lundell) Jülich & Stalpers	MSK-F 4723	MK575208	Yurchenko et al. 2020	Belarus
K. stereicola (Bres.) Nakasone	Blackwell 2141	KY081797	Riebesehl & Langer 2017	USA, Louisiana
K. subalutacea (P. Karst.) Jülich & Stalpers	KAS-GEL 2196	DQ340341	Yurchenko et al. 2020	Norway
K. subefibulata (Jia J. Chen & L.W. Zhou) Riebesehl & E. Langer	Dai 10803	KT989971	Chen et al. 2016	China
K. subglobosa (Sheng H. Wu) Hjortstam	Wu 890805-2, Holotype	KY081798	Riebesehl & Langer 2017	Taiwan
Lyomyces pruni (Lasch) Riebesehl & E. Langer	GB-0090287	MK575211	Yurchenko et al. 2020	Sweden
L. sambuci (Pers.) P.Karst.	KAS-JR7	KY800402	Yurchenko et al. 2017	Germany
Skeletocutis odora (Peck ex Sacc.) Ginns	KAS-MMS 7223	MK575212	Yurchenko et al. 2020	Czech Republic
Xylodon flaviporus (Berk. & M.A.Curtis ex Cooke) Riebesehl & Langer	FR-0249797	MH880201	Riebesehl et al. 2019	Réunion
X. quercinus (Pers.) Gray	Otto Miettinen 15050,1 (H 6013352)	KT361632	Ariyawansa et al. 2015	Finland

DBH 110 cm, 26 Aug. 2015 leg. J. Holec, det. Z. Pouzar, JH 225/2015 (PRM 935431); ibid., segment BP1g, 1080 m a.s.l., on fallen trunk of *Picea abies* (RILOG ID 108794), decay stage 2, DBH 110 cm, 26 Aug. 2015 leg. J. Holec, det. Z. Pouzar, JH 201/2015 (PRM 935410); ibid., 28 Sep. 2015 leg. J. Holec, det. Z. Pouzar, JH 386/2015 (PRM 935571); ibid., segment BP1d, 965 m a.s.l., on fallen trunk of *Picea abies* (RILOG ID 104782), decay stage 5, DBH 100 cm, 5 Jun. 2017 leg. et det. J. Běťák (JB17-ŠUM175/4); ibid., 27 Jul. 2017 not. J. Běťák; ibid., segment BP1f, 1070 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 110492), decay stage 4, DBH 113 cm, 7 Jun. 2017 leg. et det. J. Holec, JH 54/2017 (PRM 953314), 27 Jul. 2018 leg. J. Holec, det. J. Běťák, JH 99/2018 (PRM 953129), 18 Sep. 2018 leg. J. Holec, det. J. Běťák, JH 274/2018 (PRM 953195); ibid., segment BP1e, 1045 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 103945), decay stage 3, DBH 110 cm, 6 Jun. 2017 leg. et det. J. Holec, JH 31/2017 (PRM 953298), 19 Sep. 2018 leg. J. Holec, det. J. Běťák, JH 281/2018 (PRM 953198); ibid., segment BP1d, 955 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 103372), decay stage 3, DBH 100 cm, 18 Nov. 2019 leg. et det. J. Holec, JH 151/2019 (PRM 953238); ibid., segment 1g, 1042 m a.s.l., on fallen trunk of *Picea abies* (RILOG ID 110109), decay stage 4, DBH 30 cm, 19 Sep. 2020 leg. et det. J. Běťák (JB2020-BOU7/16); ibid., segment 1g, 1073 m a.s.l., on fallen trunk of *Picea abies* (RILOG ID 109630), decay stage 3, DBH 100 cm, 19 Sep. 2020 leg. et det. J. Běťák (JB2020-BOU13/47).

Novohradské hory Mts., Pohorská ves, Žofínský prales NNR, natural montane beech-fir-spruce forest, 761 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 112245), decay stage 4, DBH 120 cm, 17 Aug. 2017 leg. et det. M. Beran (CB 21791); ibid., 816 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 108519), decay stage 4(–5), DBH 130 cm, 24 Aug. 2017 leg. J. Hlásek, det. M. Beran (CB 21792); ibid., 814 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 109867), decay stage 3, DBH 99 cm, 24 Aug. 2017 leg. J. Hlásek, det. M. Beran (CB 21793); ibid., 792 m a.s.l., on fallen trunk of ?*Picea abies* (RILOG ID 101615), decay stage 3, DBH 110 cm, 25 Aug. 2017 leg. et det. M. Beran (CB 21794); ibid., 758 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 111963), decay stage 4, DBH 120 cm, 25 Aug. 2017 leg. et det. M. Beran (CB 21795); ibid., 812 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 105115), decay stage 4(–5), DBH 100 cm, 26 Aug. 2017 leg. et det. M. Beran (CB 21796); ibid., 763 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 112515), decay stage 4, DBH 63 cm, 29 Aug. 2017 leg. et det. M. Beran (CB 21797); ibid., 30 Sep. 2017 leg. et det. M. Beran, CB 21800; ibid., 24 Nov. 2020 leg. et det. M. Beran (CB 23400); ibid., 748 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 111783), decay stage 4, DBH 90 cm, 29 Aug. 2017 leg. et det. M. Beran (CB 21798); ibid., 792 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 103774), decay stage 5, DBH 110 cm, 2 Sep. 2017 leg. et det. M. Beran, CB 21799.

Fig. 1. a–d. Macroscopic appearance of *Kneiffiella curvispora*: a. hymenium in parallel rows on strongly decayed wood in cavity of lying trunk of *Abies alba*, JB20/337, photo J. Běťák; b–c. parts of large and compact fruitbodies from the bottom parts of trunks, JB20/337, photo J. Běťák (b), PRM 935571 (sequenced material), photo J. Holec (c); d. detail of aculei, JB20/337, photo J. Běťák; e. *Kneiffiella alutacea*, Javoříčko, Špraněk NNR, on strongly decayed trunk of coniferous tree, 8 Sep. 2020, JB20/321, photo J. Běťák (scale bar = 10 mm).


a
b
c
d
e

Moravskoslezské Beskydy Mts., Horní Lomná, Mionší NNR, natural montane beech-fir(-spruce) forest, 862 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 1576), decay stage 4, DBH 100 cm, 10 Sep. 2015 leg. et det. J. Běťák (JB15/997); ibid., 868 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 520), decay stage 5, DBH 120 cm, 10 Sep. 2015 leg. et det. J. Běťák (JB15/1013); ibid., 849 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 1876), decay stage 3, DBH 110 cm, 10 Sep. 2015 leg. et det. J. Běťák (JB15/1018). – Bílá, Salajka NNR, natural montane beech-fir-(spruce) forest, 769 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 100138), decay stage 3/4, DBH 85 cm, 29 Sep. 2015 leg. M. Kříž, det. Z. Pouzar (PRM 935240); ibid., 743 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 100190), decay stage 4/5, DBH 100 cm, 29 Aug. 2015 leg. M. Kříž, det. Z. Pouzar (PRM 935841); ibid., 30 Sep. 2015 leg. M. Kříž, det. Z. Pouzar (PRM 935787); ibid., 789 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 100363), decay stage 4/5, DBH 80 cm, 28 Aug. 2015 leg. M. Kříž, det. Z. Pouzar (PRM 934726); ibid., 15 Oct. 2019 leg. et det. J. Běťák, JB-SAL2019-11/8; ibid., 751 m a.s.l., on fallen trunk of *Abies alba* (RILOG ID 100805), decay stage 4, DBH 55 cm, 7 May 2019 not. J. Běťák; ibid. 1 Oct. 2019 leg. et det. J. Běťák (JB-SAL2019-19/29); ibid., 10 Sep. 2020 leg. et det. J. Běťák (JB20/337); ibid., on fallen trunk of *Picea abies* (RILOG ID 100950), decay stage 3/4, DBH 80 cm, 1 Oct. 2019 leg. et det. J. Běťák (JB-SAL2019-19/6); ibid., on fallen trunk of *Abies alba* (RILOG ID 101380), decay stage 4/5, DBH 20 cm, 17 Oct. 2019 leg. et det. J. Běťák (JB-SAL2019-4/9); ibid., on fallen trunk of *Abies alba* (RILOG ID 101483), decay stage 4, DBH 87 cm, 1 Oct. 2019 leg. et det. J. Běťák (JB-SAL2019-17/1); ibid., on fallen trunk of *Abies alba* (RILOG ID 101877), decay stage 3/4, DBH 87 cm, 16 Oct. 2019 leg. et det. J. Běťák (JB-SAL2019-20/1); ibid., on fallen trunk of *Abies alba* (RILOG ID 102199), decay stage 4, DBH 76 cm, 17 Oct. 2019 leg. et det. J. Běťák (JB-SAL2019-18/2); ibid., on fallen trunk of *Abies alba* (RILOG ID 102625), decay stage 4, DBH 45 cm, 17 Oct. 2019 not. J. Běťák; ibid., on fallen trunk of *Abies alba* (RILOG ID 999998), decay stage 4, DBH 20 cm, 17 Oct. 2019 leg. et det. J. Běťák (JB-SAL2019-17/24).

Slovakia

Veporské vrchy Mts., Klenovský Vepor NNR, ca 170 m SE of the top of Mt. Klenovský Vepor, natural montane beech-fir-spruce forest, 1220 m a.s.l., on fallen trunk of *Abies alba*, decay stage 4, 11 Oct. 2019 leg. J. Běťák, det. J. Běťák et L. Zíbarová (PRM 954540), dupl. in herb. L. Zíbarová.

Phylogeny

The aligned ITS datamatrix contained 28 taxa and 864 positions. The used positions amounted to 406 in the ML analysis. The best model suggested by MEGA7 was the Tamura-Nei model + G + I. ML topology with BS values is presented in Fig. 2. The phylogram includes 17 sequences of *Kneiffiella* specimens and strains, of which two were generated in this study. Sequences of *K. curvispora* cluster together (BS = 100) and have a significant distance to all other *Kneiffiella* sequences.

DNA sequences of *Kneiffiella curvispora* are shown for the first time in an ITS-based phylogeny based on complete ITS sequences. Larsson et al. (2006) calculated the first phylogenetic tree with a sequence of *K. curvispora*, but they only used the ITS2 part together with 28S. According to the findings by Larsson et al. (2006), this species forms also a single lineage in the ITS-based tree. All three used sequences of specimens from Norway, the Czech Republic and Slovakia are identical which confirms their identification as the same species.

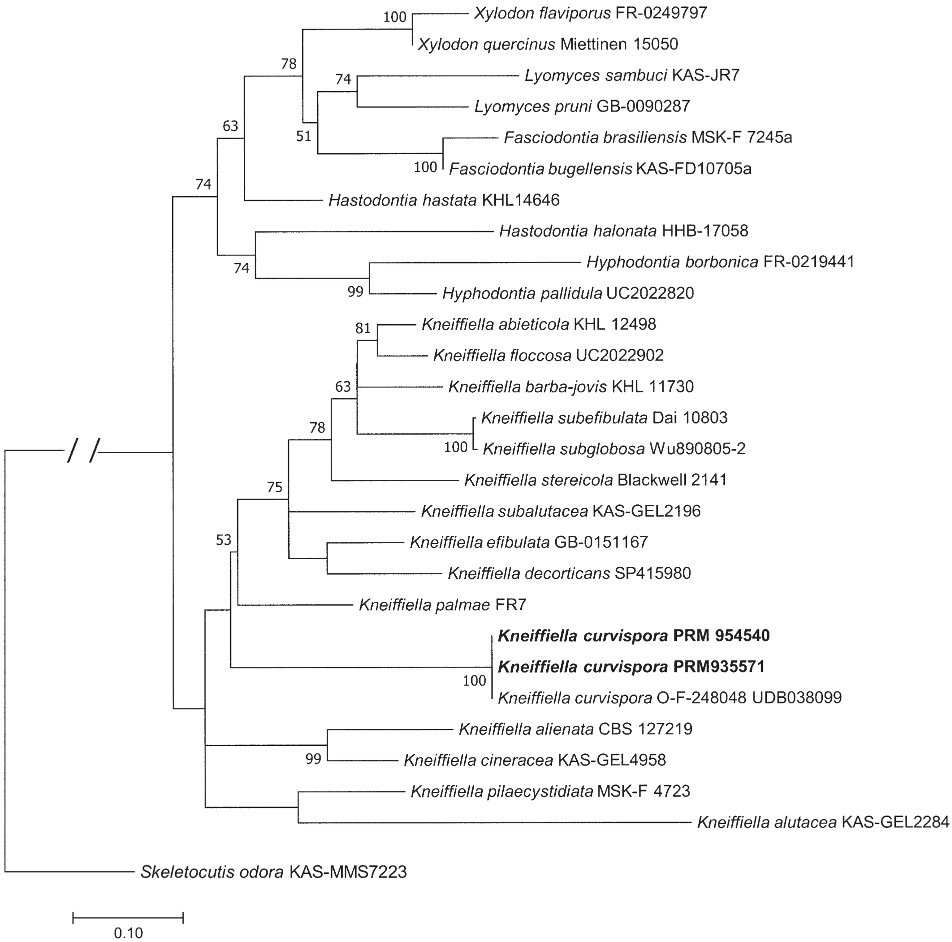


Fig. 2. Maximum Likelihood phylogram for *Kneiffiella* and related species based on ITS sequences. Numbers above branches show bootstrap (BS) support. Only BS values of over 50 are shown. The scale bar indicates the number of substitutions per nucleotide position. Newly generated sequences used in this calculation are given in bold.

Phenology

The species may occasionally form basidiomes already early May and may rarely occur until late November, but the peak of fructification is from late August to mid-October (Fig. 3). In a few cases, we also documented two fructification periods during the year with a summer break (June – July and September). The species can persist in the trunks for at least 4 years, as evidenced by repeated records from Salajka NNR. Thanks to its microhabitat preferences (see below), it can even be recorded in very dry years and periods, as indicated by the number of records in 2015, when the Czech Republic was hit by catastrophic drought.

Distribution in Central Europe

The species is undoubtedly recorded very rarely in Central Europe. It is reported from Rothwald in the Austrian Kalkalpen (both Großer and Kleiner Urwald) (Dämon 2000, Dämon 2001, Dämon & Krisai-Greilhuber 2017) and the Bavarian Forest National Park (fungi-without-borders.eu) and Hornberg in the Northern Black Forest in Germany (Grosse-Brauckmann 1990). From the Carpathian Mountains, 4 collections are known to us – three of them come from Poland (Babia Góra, Beskid Sądecki, Biesczady Mts.) (Telenius 2016a, Telenius 2016b, Gierczyk et al. 2019) and one from close to Voroneţ (Stânişoara Mts.) in Romania (Hallenberg & Thoma 1983). Our collection from Kleno-

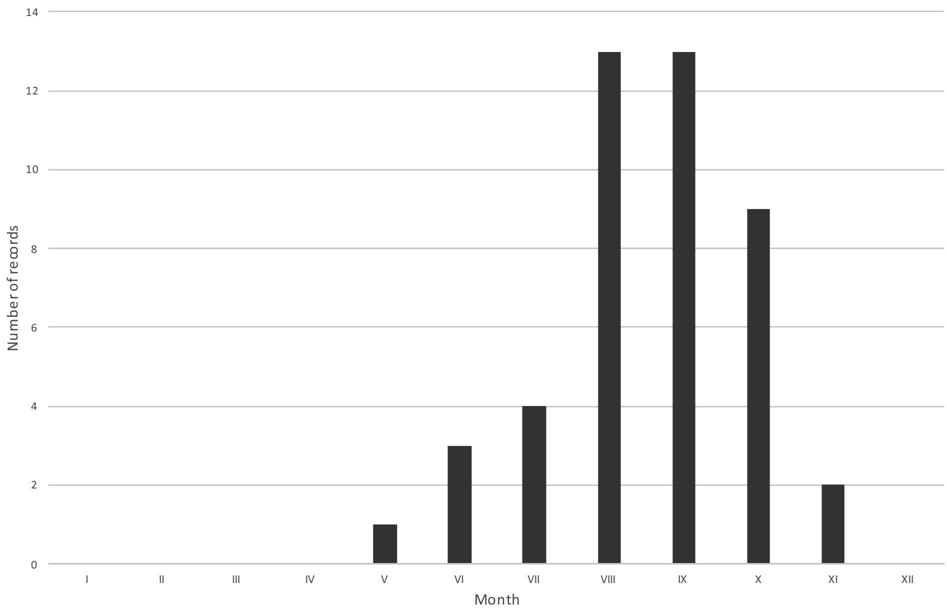


Fig. 3. Number of records of *Kneiffiella curvispora* in various months of the year (based on collections studied).

vský Vepor NNR in the Veporské vrchy Mts. listed above probably represents the first record of *K. curvispora* from Slovakia.

In the Czech Republic, the first record of *K. curvispora* comes from Boubínský prales in the Šumava Mts. and was made by Z. Pouzar on 9 Aug. 1956 (PRM 847477), 13 years before its description as a new species to science (Eriksson & Hjortstam 1969). Although left unidentified for a long time, Pouzar's find is probably the first collection of the species in the world. Domański, who collected the same species (labelled with the provisional, never published name '*Odontia pseudosudans* sp. n.') in Białowieża Forest in the same year, was about three weeks later (Karasiński et al. 2009). After Pouzar's second find in 1970 (PRM 845358), the species remained forgotten and unconfirmed in Boubínský prales until 2013 (Holec et al. 2015a). Recent collections from this site come from several microlocalities (probably due to the increasing intensity and detailedness of field research) (Holec et al. 2015a, Holec et al. 2020, Holec & Kučera 2020). Numerous recent collections also come from Žofínský prales NNR in the Novohradské hory Mts., which is the oldest forest reserve in continental Europe and is famous for its rich mycobiota (Svrček & Kubička 1964, Svrček & Kubička 1971, Beran 2004, Beran 2005). Another Czech record comes from Diana NR in the Český les Mts. (Kelnerová 2018). Recently, *K. curvispora* was discovered and repeatedly also collected in two well-known forest reserves in the Czech part of the Western Carpathians (Moravskoslezské Beskydy Mts.; Mionší and Salajka NNRs), which both belong to the most valuable mixed beech-fir

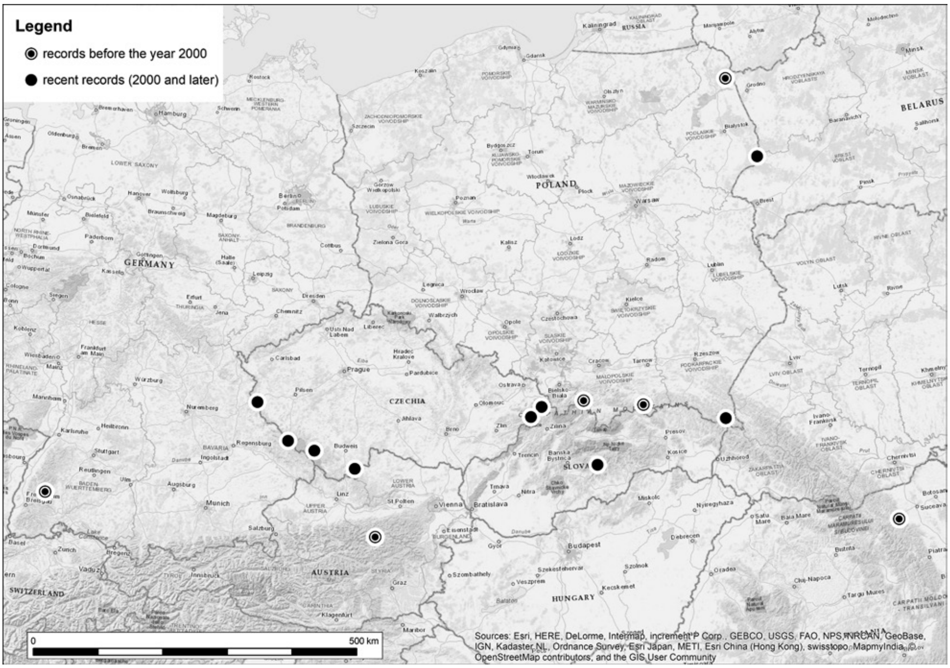


Fig. 4. Distribution of *Kneiffiella curvispora* in Central Europe.

forests in this part of the Carpathians. Especially in the latter one, the species population is remarkably abundant.

The species is also published (as *Chaetoporellus curvisporus*) from Podyjí National Park (Antonín & Vágner 2000) and mentioned in an unpublished report of a survey of lignicolous fungi in the Velký Špičák NNR in the Bohemian-Moravian Highlands (Vampola 1996), but both of these collections actually represent *Kneiffiella alutacea* (rev. J. Běťák). For a distribution map of *Kneiffiella curvispora*, see Fig. 4.

Ecology

Autecology – substrate and habitat

Based on our collections, *Kneiffiella curvispora* is a late inhabitant of gymnosperm wood, colonizing mainly large decaying trunks (DBH 20–130 cm, average 87 cm) of *Abies alba* and *Picea abies* in (moderately advanced to) advanced stages of decomposition (3–)4(–5)

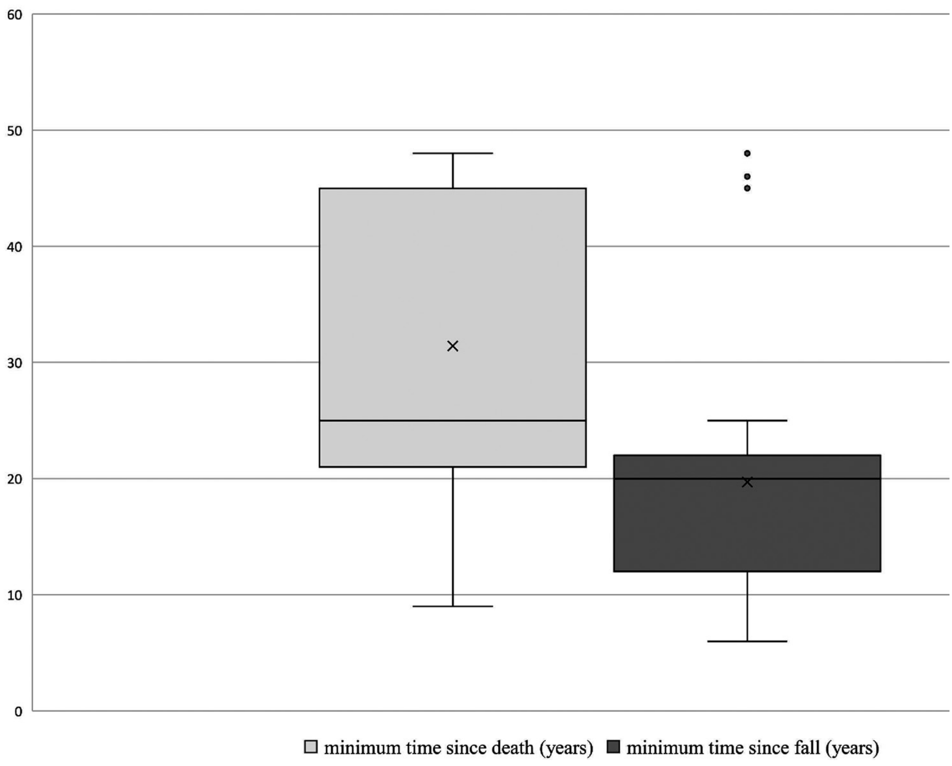


Fig. 5. Minimum time since death/fall (in years) of trunks inhabited by *K. curvispora* based on data in RILOG tree database.

in virgin or natural mixed (sub)montane beech-fir(-spruce) forests (for scale of forest naturalness used in the Czech Republic, see e.g. Holec et al. 2015b). We documented the species occurrence on 32 trunks at 4 localities, which all represent the best preserved sites of montane mixed forest in the country. Most of the trees inhabited by *Kneiffiella curvispora* are demonstrated to have fallen more than 20 years ago and some of them probably died more than 50 years ago (see Fig. 5 and Table 1 in electronic supplement). The species was only exceptionally recorded on trees deceased recently (up to 20 years). Usually, the trunks lie flat on the ground, the bark is almost completely absent, and the moss cover is rather high (Fig. 6).

On the inhabited trunks, the basidiomes occur almost exclusively on strongly decayed wood without bark (and usually also without mosses). The species prefers shady microhabitats with long-time presence of wet soft wood, such as cavities, undersides and eroded lateral sides of trunks, where the evaporation is low and humidity high throughout most of the year (Figs. 7, 8). Finds on trunks of small diameter are rather rare. For example, in Salajka NNR, where 59 *Abies* trunks in decay stages 3–5 and of an average diameter of 41.7 cm were inspected, *K. curvispora* was detected on 9 trunks with an average diameter of 61.7 cm. In individual cases, when the trunk was rather thin, it was often lying directly in a forest spring or partly in a stream (Fig. 8).

Records from other microhabitats, such as a compact surface on topsides of trunks and remnants of branches still attached to the trunk, are also very unusual. The species is

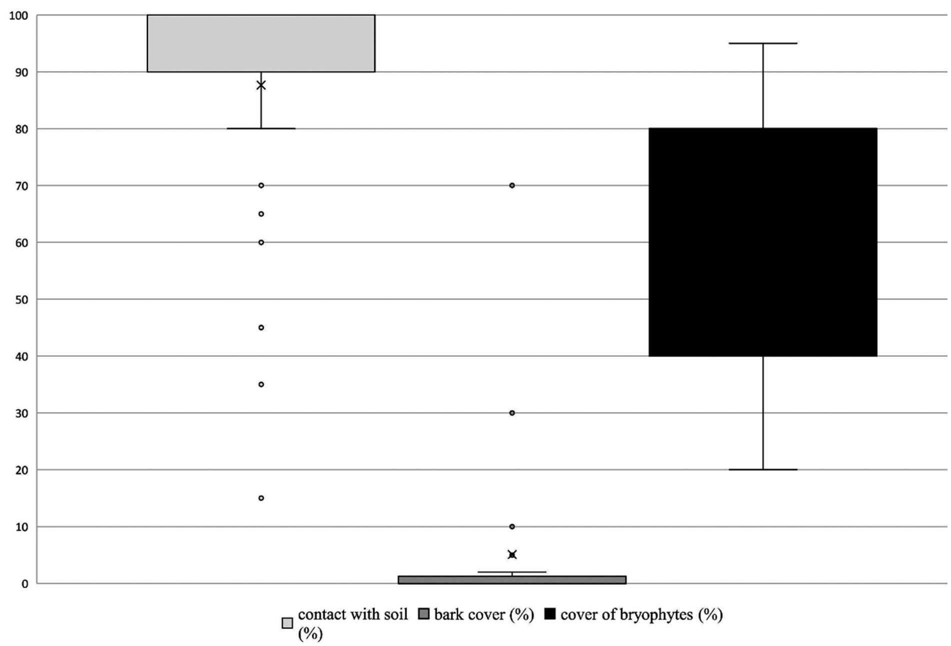
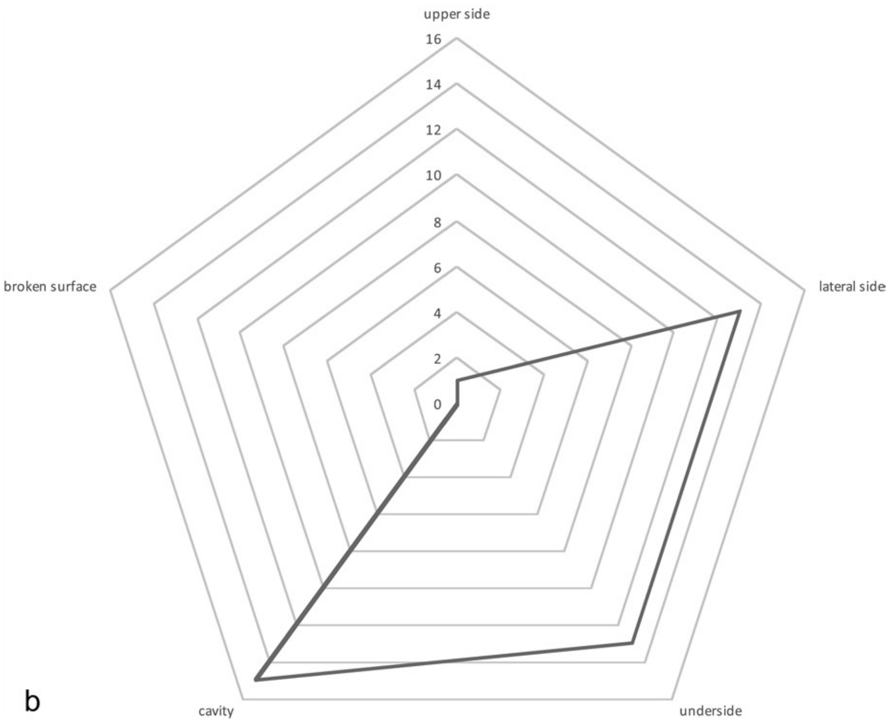


Fig. 6. Basic ecological features of trunks inhabited by *Kneiffiella curvispora* (n=32).


wood decay 1
20
18
16
14
12
10
8
6
4
2
0
wood decay 2
wood decay 3
wood decay 4
wood decay 5

a


upper side
16
14
12
10
8
6
4
2
0
lateral side
underside
cavity
broken surface

b

found equally in lower and upper (crown) parts of lying trunks, but has never been recorded on a standing snag or a stump (see Table 1 in electronic supplement). Based on our data, the species occurs in a rather wide range of altitudes, from 500 (Diana) up to 1220 m a.s.l. (Klenovský Vepor, Slovakia). Although we and our colleagues (D. Dvořák, M. Kříž, L. Zíbarová) have undertaken several methodologically similar field studies in many areas of old-growth montane spruce forests at higher altitudes in the Czech Republic and Slovakia during recent years (Krkonoše Mts., Hrubý Jeseník Mts., High and Low Tatras Mts., Veľká Fatra Mts., Poľana Mts., Slovenské Beskydy Mts.), we have surprisingly never found the species in this kind of natural habitat. *K. curvispora* seems therefore to be primarily associated with fir in Central Europe, while spruce serves as a secondary substrate at localities where these tree species co-occur. Although this hypothesis contradicts the data on the species' optimum in Fennoscandia where fir is missing, there is a number of boreo-montane corticioid fungal species (for examples, see subchapter Synecology below) having similar substrate requirements and/or a similar distribution pattern.

The opposite pattern is represented by rather few specialists. For example, *Hyphoderma velatum* nom. prov. (see Dämon 2000), *Hypochnicium cymosum* (D.P. Rogers & H.S. Jacks.) K.H. Larss. & Hjortstam, *Paullicorticium allantosporum* J. Erikss., *Pseudoxenasma verrucisporum* K.H. Larss. & Hjortstam are tiny and probably competitively weak corticioid species, which seem to be strictly associated in Central Europe with dead wood of spruce in montane spruce forests at high altitudes (Dämon 1997, Dämon 2000, Blaser 2016 and also our field experience). To explain, why certain boreo-montane species avoid the habitat of montane spruce forests in Central Europe, is beyond the focus of this case study. Among others, it may be related to the evolution of interspecies relationships during the postglacial spread of spruce and fir (for an overview, see e.g. Douda et al. 2015), or it could be a reflection of human interventions which have disrupted the spatial and temporal continuity of montane forest ecosystems.

To date, *K. curvispora* has never been collected at lower elevations in deep river valleys at well-preserved and frequently visited forest localities with climatic inversion and relict natural occurrence of silver fir and/or Norway spruce, from which some other so-called old-growth forest species are documented (e.g. *Antrodiella citrinella* Niemelä & Ryvarden, *Gymnopilus bellulus* (Peck) Murrill, *Rhodofomes roseus* (Alb. & Schwein.) Kotl. & Pouzar, *Phellinus nigrolimitatus* (Romell) Bourdot & Galzin, *Skeletocutis odora* (Peck ex Sacc.) Ginns) (Běťák 2015, Kout & Vlasák 2009, Holec 2009, Holec et al. 2018). The reasons of this fact may include less attention paid to corticioid fungi in standard mycological surveys, but also the low volume of dead fir/spruce wood, small area and different climatic conditions (generally greater dryness) at these habitats. Diana NR in the Český les Mts. represents the exception, both in terms of altitude (500–530 m a.s.l.), geomorphology (rather flat terrain) and management. It is an isolated remnant of a relatively well-preserved old beech-spruce forest surrounded by cultural spruce stands (former game reserve with selective logging and bark-beetle breakout sanitation during past dec-

Fig. 7. Number of occurrences of *Kneiffiella curvispora* fruitbodies on wood in different stages of decay (left) and in specific microhabitats (right) on the studied trunks.


a
b
c
d
e
f

ades) with admixture of other tree species, including silver fir in the past (Vrška et al. 2012). The substrate of the collection from Diana is strongly decayed and was indicated as 'beech' (Kelnerová 2018), but turned out to be coniferous wood after microscopic revision.

According to data from the Czech Republic, *K. curvispora* seems to be strictly associated with the best preserved remnants of natural montane mixed beech-fir(-spruce) forests, representing various vegetation units of the *Fagion sylvaticae* alliance. Such a summarization is supported by sporadic reports of the species from other countries in Central Europe. The first locality of the species from Slovakia mentioned above (Klenovský Vepor NNR) is one of the best preserved mixed montane beech-fir-spruce forests in the country (http://pralesy.sk) with occurrence of many other rare virgin forest fungi. In Austria, the only two localities are situated in montane (900–1100 m a.s.l.) natural mixed beech-fir-spruce forests (Dämon 2000). In Germany the species is recently known from Bavarian Forest National Park, where it was collected three times on *Abies* trunks close to Zwieseler Waldhaus (www.fungi-without-borders.eu). In Poland, one locality from the Carpathians mentioned above (Labowiec Reserve close to Nowy Sacz) is situated in a natural beech-fir forest at an altitude of 800–1000 m a.s.l., another one is from a *Picea* trunk, but is localized unclearly (Sucha Beskidzka in Babia Góra National Park) (Telenius 2016a, b). A recent collection from the Biesczady Mts. (Gierczyk et al. 2019) comes from an unknown substrate ('branch') from a well-preserved beech forest (ca 800 m a.s.l.) with admixture of *Abies* and maybe also *Picea* (Gierczyk in litt.). Other localities in Poland known to us are from Białowieża virgin forest (on *Picea abies*) (Langer 1994, Karasiński et al. 2009) and from Starożyn close to Augustów (unpublished herbarium collection: PRM 843747). The last two localities represent natural hemiboreal forest and are situated outside the *Abies alba* distribution range. The only Romanian record comes from a mixed *Abies*-*Picea* forest close to the Voroneţ monastery, but is inaccurately localized (Hallenberg & Toma 1987). Most probably, it does not represent a typical montane spruce forest.

Besides the record from Diana NR (see above), we know of a single collection of the species from man-influenced habitat outside Fennoscandia, namely Hornberg in Schwarzwald (Germany), where the species was collected in a cavity of a *Picea* stump (Grosse-Brauckmann 1990).

Fig. 8. Habitats of *Kneiffiella curvispora*: a, d. thin, strongly decayed trunk of *Abies alba* (RILOG ID 999998) in forest spring, Salajka NNR, 10 Sep. 2020 photo J. Běťák; b. large trunk of *Picea abies* (RILOG ID 108794) dead for more than 43 years, Boubínský prales NNR, 30 Apr. 2015 photo J. Holec; c. huge broken trunk of *Abies alba* (RILOG ID 1576) with still hard wood on the surface, but strongly decayed heartwood, Mionší NNR, 24 May 2015 photo D. Dvořák; e. cavity and bottom part of brown-rotted trunk of *Abies alba* with fruitbodies of *K. curvispora* (RILOG ID 101877), Salajka NNR, 10 Sep. 2020 photo J. Běťák; f. rather recently (14±5 years ago) fallen Abies alba (RILOG ID 109867) with high moss cover, Žofínský prales NNR, 30 Sep. 2020 photo M. Beran.

Synecology

Altogether 167 fungal species were recorded on 30 trunks inhabited by *K. curvispora* and studied mycosociologically (see Table 2 in electronic supplement). Obviously, *K. curvispora* does not appear to grow in a clearly definable association with other fungal species. Its occurrence seems rather to be conditioned by a suitable microhabitat and perhaps also uninterrupted availability of the preferred type of substrate (medium to strongly decayed trunks of *Abies*/*Picea*) in sufficient amount. We also have no evidence that *K. curvispora* requires prior presence of a dominant fungal species in the succession process of wood decay. It is found on both brown cubic rotten wood decayed by *Fomitopsis pinicola* (Sw.) P. Karst. and on white laminar rot caused by *Phellinus nigrolimitatus*, but also on trunks with absence of these or other species known to be predecessors in wood decay processes (Jönsson et al. 2008, Pouska et al. 2013, Ottosson et al. 2014, Holec et al. 2020). However, in order to describe the successive development of communities on trunks inhabited by *K. curvispora* more accurately, we would need to have monitored the trunks several decades back in time.

Only 8 fungal species (4.8%) were recorded at all studied sites (*Calocera viscosa* (Pers.) Fr., *Fomitopsis pinicola*, *Galerina stordalii* A.H. Sm., *Hydropus marginellus* (Pers.) Singer, *Mycena maculata* P. Karst., *Mycena stipata* Maas Geest. & Schwöbel, *Mycena viridimarginata* P. Karst. and *Physisporinus sanguinolentus* (Alb. & Schwein.) Pilát), which indicates a strong effect of locality, varying monitoring periods and/or differing methods of field survey. The results in this subchapter are rather inconsistent for these reasons. All the most frequently accompanying species are common fungi with rather broad ecological requirements. *Calocera viscosa*, *Lactarius subdulcis* (Pers.) Gray, *Mycena stipata*, *Galerina hypnorum* (Schrank) Kühner and *Physisporinus sanguinolentus* were all recorded on at least 12 studied trunks. Of the corticioid species, which were studied (with different intensity) on only 20 trunks, *Aphanobasidium pseudotsugae* (Burt) Boidin & Gilles and *Resinicium furfuraceum* (Bres.) Parmasto were the most common. Mycorrhizal fungi occurred quite often on trunks inhabited by *K. curvispora*, which indicates an advanced stage of trunk disintegration. A number of 21 trunks out of the 30 studied were inhabited by at least one mycorrhizal species, but some trunks by up to 6 species. A total of 103 accompanying species (62%) out of 167 represent singletons and doubletons, which corresponds well with datasets from both large *Abies* and *Picea* trunks from Boubínský prales virgin forest (Holec et al. 2020, Holec & Kučera 2020). For a complete list of accompanying species, see Table 2 in the electronic supplement.

Many other species of conservation value have been recorded on the studied trunks. Altogether 23 red-listed species (according to Holec & Beran 2006) as well as some other generally rare species were recorded (see Table 2). Although none of these apparently seeks or prefers the presence of *K. curvispora* (or vice versa), the substrate and/or habitat requirements of these species appear to overlap partially. The most frequently co-occurring red-list species was *Gymnopilus bellulus*, which was recorded on 8 trunks out of the 30 studied.

Table 2. Accompanying species of conservation value (red-listed and generally rare) recorded on studied trunks inhabited by *Kneiffiella curvispora*. BOU = Boubínský prales NNR, MIO = Mionší NNR, SAL = Salajka NNR, ZOF = Žofínský prales NNR. The number in brackets indicates the number of trunks inhabited by *K. curvispora* at each locality.

Species	Red-list category (Holec & Beran 2006)	Locality (number of inhabited trunks)	Tree species	Decay stage of occupied trunks
Antrodiella citrinella	EN	BOU (2)	*Picea*	3
Baeospora myriadophylla	CR	ZOF (1)	*Abies*	3
Botryobasidium intertextum	NT	BOU (1), SAL (1)	*Abies*	3, 4/5
Botryobasidium medium	EN	BOU (1), MIO (1), SAL (1)	*Picea*, *Abies*	2, 3, 4
Callistosporium pinicola	–	BOU (1), ZOF (1)	*Abies*	3, 4
Camarops tubulina	NT	BOU (2)	*Picea*	3
Clavulicium macounii	EN	BOU (1)	*Abies*	3
Clitocybula familia	EN	ZOF (1)	*Abies*	4
Clitocybula lacerata	EN	BOU (1)	*Abies*	3
Entoloma tjallingiorum	EN	BOU (1)	*Abies*	3
Galerina pruinatipes	–	BOU (2), SAL (1)	*Abies*	3, 4
Galerina stordalii	–	BOU (2), MIO (1), SAL (1), ZOF (1)	*Picea*, *Abies*	2, 3, 4, 4/5
Globulicium hiemale	CR	MIO (3), SAL (1)	*Abies*	3, 4, 5
Gymnopilus bellulus	VU	BOU (3), SAL (3), ZOF (2)	*Picea*, *Abies*	3, 4, 4/5
Hericium flagellum	NT	ZOF (2)	*Abies*	3, 4/5
Hydropus atramentosus	CR	ZOF (1)	*Abies*	3
Hymenochaete fuliginosa	EN	BOU (1), MIO (1), SAL (1)	*Picea*, *Abies*	3, 3/4
Hyphoderma involutum	–	MIO (1)	*Abies*	4
Kavinia alboviridis	?EX	MIO (1)	*Abies*	3
Melanophyllum haematospermum	NT	MIO (3), SAL (1)	*Abies*	3, 4, 5

Table 2. cont.

Species	**Red-list category (Holec & Beran 2006)**	**Locality (number of inhabited trunks)**	**Tree species**	**Decay stage of occupied trunks**
Mycena laevigata	VU	BOU (2), ZOF (3)	*Picea*, *Abies*	2, 3, 4
Phellinus nigrolimitatus	NT	BOU (3)	*Picea*	2, 3, 4
Phlebia centrifuga	EN	BOU (1), SAL (2)	*Picea*, *Abies*	3, 3/4, 4
Phlebia cremeoalutacea	–	BOU (1), SAL (1)	*Abies*	3, 4
Phlebia subulata	–	MIO (1)	*Abies*	4
Pseudoplectania melaena	EN	BOU (1), SAL (1)	*Abies*	3, 4
Pseudorhizina sphaerospora	CR	BOU (1)	*Picea*	3
Resupinatus striatulus	–	BOU (1), ZOF (1)	*Picea*, *Abies*	3, 4/5
Rigidoporus crocatus	EN	ZOF (3)	*Abies*	3, 4, 4/5
Rigidoporus undatus	–	SAL (3)	*Abies*	4, 4/5
Sphaerobasidium minutum	–	BOU (1)	*Picea*	4
Tubulicrinis globisporus	?EX	MIO (2)	*Abies*	3, 4

Dämon (2000) also gives some noteworthy corticioid species growing in the close vicinity of two *K. curvispora* records in Rothwald (Austria): *Athelopsis subinconspicua* (Litsch.) Jülich, *Gloiothele citrina* (Pers.) Ginns & G.W. Freeman (=*Vesiculomyces citrinus*), *Hyphoderma cremeoalbum* (Höhn. & Litsch.) Jülich, *Hyphodontia abieticola* (Bourdot & Galzin) J. Erikss. (=*K. abieticola*), *Hyphodontia alienata* (S. Lundell) J. Erikss. (=*K. alienata*), *Hyphodontia spathulata* (Schrad.) Parmasto (=*K. spathulata*), *Myxarium podlachicum* (Bres.) Raitv., *Phlebia centrifuga* P. Karst., *Phlebia georgica* Parmasto, *Phlebia subulata* J. Erikss. & Hjortstam, *Steccherinum subcrinale* (Peck) Ryvarden, *Thanatephorus fusisporus* (J. Schröt.) Hauerslev & P. Roberts, *Tubulicrinis borealis* J. Erikss., *Xenasma pruinosum* (Pat.) Donk. However, occurrence of these species is not directly related to the trunks inhabited by *K. curvispora*. Most of these species are also known from some of the *K. curvispora* localities in the Czech Republic presented here (Dvořák & Běťák 2016, Kříž 2016, Holec et al. 2015a, Holec et al. 2020, Holec & Kučera 2020).

Having very small allantoid basidiospores, *K. curvispora* meets criteria of typical saprotrophic and lignicolous species also from the perspective of spore morphology as proposed by Calhim et al. (2018). Relatively large, long-living fruitbodies and small spore dimensions should further indicate high spore production and good dispersion ability. However, its clear preference for strongly decayed wood of large dimensions and for shady, wet and closed microhabitats with bad long-distance spore propagation suggests that the species rather behaves as a C- than a r-strategist.

Bryophytes and lichens

Some trunks inhabited by *K. curvispora* were also inspected for lichens and bryophytes. In Salajka NNR, only common lichen species of forests were recorded on 6 *Abies* trunks. *Coenogonium pineti* (Ach.) Lücking & Lumbsch, *Micarea micrococca* (Körb.) Gams ex Coppins and *Placynthiella icmalea* (Ach.) Coppins & P. James were the most common. Of bryophytes, common forest species such as *Dicranodontium denudatum* (Brid.) E. Britton, *Dicranum montanum* Hedw., *D. scoparium* Hedw., *Herzogiella seligeri* (Brid.) Z. Iwats., *Hypnum pallescens* (Hedw.) P. Beauv. and *Tetraphis pellucida* Hedw. dominated on most of the 7 studied trunks. Occasionally, some more sensitive liverwort species occurred, e.g. *Nowellia curvifolia* (Dicks.) Mitt., *Riccardia* spp., *Calypogeia* spp. and the endangered *Harpanthus scutatus* (F. Weber & D. Mohr) Spruce.

Threats and protection

The localities in the Czech Republic and Slovakia represent most of the few recent sites inhabited by *K. curvispora* in Central Europe. As almost all localities of the species are located in old-growth forests with long-term spontaneous development, non-intervention management seems to be suitable for the protection of its populations. However, the gradual decline of fir (and spruce) in favour of the spreading beech (Šamonil & Vrška 2007, Vrška et al. 2012) may pose a long-term threat to it (as well as to many other species with a similar ecology).

Whereas strictly associated with unmanaged montane forests in Central Europe, in Scandinavia, where *K. curvispora* has a higher population density, Kubart et al. (2016) detected the species using 454-sequencing in *Picea abies* stumps and showed that it may persist at a locality for up to 20 years even after clear-cutting, at least in non-fruiting form. This is also the case with other species of conservation value like *Metulodontia nivea* (P. Karst.) Parmasto, *Perenniporia subacida* (Peck) Donk and *Postia placenta* (Fr.) M.J. Larsen & Lombard (= *Rhodonia placenta*).

K. curvispora is red-listed in Norway (VU) (Henriksen & Hilmo 2015), Sweden (VU) (SLU Artdatabanken (2020), Finland (NT) (Rassi et al. 2010) and Austria (EN) (Dämon & Krisai-Greilhuber 2017), and should also be included in the next versions of red-lists of the Czech Republic and Slovakia.

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Table of contents – Electronic Supplementary Material (ESM)

Table 1. Detailed characteristics of studied trunks inhabited by *Kneiffiella curvispora*, based on data from the RILOG tree database and partly estimated (est.) in the field; microhabitat characteristics of substrate recorded at *K. curvispora* fruitbody sites.

Table 2. Fungal species recorded on the studied trunks inhabited by *Kneiffiella curvispora*.