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Species diversity of wood-destroying fungi on Fagus sylvatica L. depending on the structure of dead wood in Western Bulgaria

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Abstract. During 2022 the stock, value and structure of the dead beech woods (*Fagus sylvatica* L.) as well as the diversity of the wood-destroying fungi were investigated in four sample areas (SA) situated in Stara Planina Mts. and Vitosha Mt. (Western Bulgaria). The total stock of dead wood in these mountains differs significantly. In SA Petrohan and Barzia (Stara Planina) that amount was 30.04-34.72 m^3 ha^{-1}, but in Tihia kat and Zlatni mostove (Vitosha) 9.93-15.35 m^3 ha^{-1} have been established. The main difference between these two groups of sample areas is the origin of the stand - seed (Stara Planina Mts.) or coppices (Vitosha Mt.). A total of 104 species of fungi were found. The SA Petrohan has the richest species composition (79 species), followed by the SA Tihia kat (29 species), SA Zlatni mostove (24) and the SA Barzia (22 species). The most numerous were the fungi species from the division Basidiomycota (76 species with 254 findings) and the most widespread among them were *Stereum hirsutum, Fomes fomentarius, S. rugosum, Trametes hirsuta, Exidiopsis calcea, Trametes versicolor*. Among the ascomycetes, 18 species were identified. Their average occurrence is the highest – 8.1 finds per species. The most common were *Hypoxylon fragiforme, Xylaria hypoxylon, Diatrype disciformis, Bisporella citrina* and *Jackrogersella cohaerens*. Ten species of the division Myxomycota only were found with average of 1.8 finds per species. The most common was *Trichia decipiens*, followed by *Ceratiomyxa fruticulosa* and *Physarum* sp.

Key words: *Fagus sylvatica* L., dead wood, fungi, Western Bulgaria.

Introduction

Forests accumulate and store large amounts of carbon (C) and a significant portion of this stock is contained in dead wood that is subject to decomposition by associated organisms, a process that contributes to CO_2 emissions (Tláskal et al., 2021). Dead wood includes standing dead trees, stumps, whole fallen trees, lying thick and thin branches, pieces of chipped wood (Bače et al., 2019) that are gradually colonized by a variety of organisms. It is believed that a tree, from the time of death to its complete decomposition, is inhabited by several to hundreds of species of mosses, worms, fungi, plants and insects. Forest fragmentation, disrupting the even distribution of dead trees, is a major barrier to the spread of many of the

deadwood-associated saproxylic species (Kacprzyk et al., 2014). Wood decomposition is a crucial process in the nutrient recycling, soil formation and carbon stock of forest ecosystems (Lonsdale et al., 2008). Wood-destroying fungi are essential to the functioning of forest ecosystems. They provide habitat for many other organisms and enable the regeneration of forests around the world.

Ódor et al. (2006) analyzed the species composition and diversity of fungal and bryophyte communities occurring on dead beech wood in beech-dominated forest reserves in five European countries (Slovenia, Hungary, the Netherlands, Belgium and Denmark). The results show that the two most important factors influencing the species composition of fungi are the stage of wood decay and the geographical region, with the former being of greater importance. Species abundance was also positively related to wood size. Species diversity increases with increasing wood diameter and is greatest at intermediate stages of decomposition. On a regional scale, available tree species, climatic conditions, cause of tree death, soil type, continuity and management history are also important factors.

Studies related to the species diversity of wood-destroying fungi in beech stands were conducted in Germany (Floren et al., 2015; Marcot et al., 2017), Denmark (Heilmann-Clausen & Christensen, 2004), Poland (Kacprzyk et al., 2014), Romania (Copoţ et al., 2020), Czech Republic (Lepinay et al., 2021).

Based on the physicochemical changes in wood and the development of fungal communities, Fukasawa (2021) categorized the decay process of dead wood in forests into three stages: early, intermediate and late. The author summarizes the following groups of fungi important in determining the type and stage of wood decay: endophytic xylariaceous ascomycetes and basidiomycetes in the early stages of decay, secondary colonizing basidiomycetes in the intermediate stages, and soft-rot ascomycetes in the late stages. The diversity of fungi associated with different types of wood decay also creates a diversity of habitats for saproxylic communities and enriches the biodiversity of forest ecosystems.

Wood-degrading fungi are the only life forms capable of breaking down wood to its original constituents, contributing significantly to the soil ecosystem. To clarify their role in soils, Tong et al. (2018) performed a bibliometric analysis of Web of Science (WOS) data for the period 1913-2020 and summarized global research related to wood-rot fungi. Their conclusion is that research in this area is mainly concentrated in Northern Europe, the USA and China.

This determines the need to expand research in other regions of the world on the distribution and relationship of decay-causing fungi with dead wood at different stages of decomposition, which is the aim of the present study.

Materials and Methods

During 2022 four sample areas (SA) were established in beech stands (*Fagus sylvatica* L.) in the two mountains in Western Bulgaria - Stara Planina Mt. (Balkan Range Mts.) and Vitosha Mt. (Table 1).

Table 1. Brief description of the objects in which sample areas have been laid

Object	**Stara Planina Mt.**		**Vitosha Mt.**	
Sample area (SA)	**Petrohan**	**Barzia**	**Tihia kat**	**Zlatni mostove**
SA №	**1**	**2**	**3**	**4**
coordinates	N 43° 07' 21.8" E 23° 07' 17.3"	N 43° 10' 39.4" E 23° 09' 11.8"	N 42°63' 13.1" E 23°22' 43.8"	N 42°61' 27.5" E 23°23' 57.8"
altitude, m	1500	650	1100	1400
exposure	S-E	N-E	N-W	S-W
slope º	18	18	15	16
composition	beech 10	beech 10	beech 7, aspen 3	beech 9, spruce 1
origin	seed	seed	coppices	coppices
age, years	120	130	90	110

In the fall of 2022, a route and detailed forest pathology survey of the dead wood available in the trial areas was conducted, incl. fallen and broken trees or branches lying on the ground; stumps and felled wood; standing dry stems and dead parts of living trees. The established findings of fruiting bodies were photographed for further identification and description in the laboratory conditions using atlases and mushroom identifiers (Garnweidner, 1996; Lamaison et al., 2005; Janssen, 2004; Stancheva et al., 2009 and others) as well as Internet sources.

The criteria for classifying the assessed wood are indicated in Table 2.

The volume of the dead wood was calculated as follows:

- standing dead wood - a sample plots with square shape and size 50/50 m (2500 m^2) were settled, the volume (m^3 ha^{-1}) was calculated with height rates tables according Poryazov et al. (2004);
- lying dead wood - method of line intersect sampling (Warren & Olsen, 1964), adapted by Lazarov et al. (2012);
- stumps - the volume of the stumps was calculated by the following formula:

$$V = \pi \times r^2 \times h$$

where: V – volume of dead stumps ($m^3.ha^{-1}$); r– radius (m); h – height of the stump (m).

Table 2. Criteria for classification of dead wood

Extent Indicator	**1**	**2**	**3**	**4**
Condition of the wood	live tree	dead standing tree	fallen tree (uprooted)	broken (on the ground)
Decay stage	wood is hard and has bark	wood is hard but >50% of bark missing	bark missing, stem softens but retains structural integrity	the stem is soft and loses its integrity
Diameter	<5 cm	5-10 cm	10-20 cm	>20 cm

Results

The results of the survey show that the stock of dead wood (Table 3) is largest in SA Petrohan – total 34.72 m^3 ha^{-1}, followed by SA Barzia – 30.04 m^3 ha^{-1}, but while in the former large-sized lying wood predominates (23.2 m^3 ha^{-1}), in the second there is the largest share of standing wood (14.84 m^3 ha^{-1}). The smallest stock is in SA Zlatni mostove – 9.93 m^3 ha^{-1}.

According to the stage of decomposition of the dead wood (Table 4), standing dead wood in an advanced stage of decomposition (stage 3-4) predominates in SA Petrohan, while a relatively even distribution of the four stages is observed in the lying dead wood and stumps. In the SA Barzia, standing and lying dead wood are in the initial stage of decomposition (1-2) and only the stumps are dominated by high degrees of decay (3-4). Only recently dead wood (1) is present in SA Tihia kat, the stumps are also in the initial phase of rotting (2), and in the lying dead one relatively evenly stages 1, 2 and 3, and less 4, were found. A similar distribution by stages of decomposition was repor-ted in SA Zlatni mostove, where a higher degree of decay (3-4) was found only in the stumps.

Table 3. Stocks of dead forest biomass in the sample areas (V, m^3 ha^{-1})

Sample area (SA)	**SA №**	**Standing biomass**	**Lying biomass**			**Stumps**	**Total**
			large size	**fine**	**total**		
Petrohan	**1**	4.5	23.2	2.5	25.7	4.52	34.72
Barzia	**2**	14.84	5.5	5.5	10	5.2	30.04
Tihia kat	**3**	0.6	7.79	6.89	14.68	0.07	15.35
Zlatni mostove	**4**	3.8	2.3	2.8	5.1	1.03	9.93

Table 4. Decomposition stages of dead wood biomass (%)

Decay stage	Petrohan	Barzia	Tihia kat	Zlatni mostove
SA	**1**	**2**	**3**	**4**
standing woody biomass				
1	-	78	100	75
2	-	22	-	25
3	80	-	-	-
4	20	-	-	-
lying woody biomass				
1	42	65	21	11
2	33	29	43	80
3	17	4	29	9
4	8	2	7	-
stumps				
1	8	13	-	-
2	31	8	100	13
3	38	21	-	37
4	23	58	-	50

A total of 104 species of fungi with 418 finds were observed for the four surveyed sites in Stara Planina and Vitosha Mts. (Table 5). The average occurrence for one species is with 4 finds (Table 6). The richest species composition was found in the SA Petrohan (79 species with a total of 184 described finds), followed by the SA Tihia kat (29 species with 96 finds), the SA Zlatni mostove (24 species with 44 finds) and the SA Barzia (22 species with 94 findings).

The largest number of described species are representatives of the division Basidiomycota (76 species with 254 findings). The average occurrence for each species is 3.3 finds, but 38 of the species (50%) were found with only one find. Only 12 species (15.8 %) have more than 5 findings.

Of the representatives of the Basidiomycota division, the most widespread are *Stereum hirsutum* (Willd.) Pers. (with 49 findings), *Fomes fomentarius* (L.) Fr. (16), *S. rugosum* Pers. (12), *Trametes hirsuta* (Wulfen) Lloyd (11), *Exidiopsis calcea* (Pers.) K. Wells (11), *T. versicolor* (L.) Lloyd (10), *Schizophyllum commune* Fr. (9), *Mycena galericulata* (Scop.) Gray (8), *Pluteus cervinus* (Schaeff.) P. Kumm. (7), *Trichaptum biforme* (Fr.) Ryvarden (6), *S. subtomentosum* Pouzar (5) and *Mycoacia livida* (Pers.) Zmitr. (5). The remaining species were identified singly or with 2-4 finds. The most common species, *Stereum hirsutum* (49), was found mainly on wood with bark (19) or with partial loss of bark (16). Only one of his finds was on decaying wood with no structural integrity or bark. The largest number of finds are on broken thin branches (5-10 cm). On broken wood with a diameter of more than 5 cm, in the initial stages of decomposition, it was also found *Schizophyllum commune* (9). *Stereum rugosum* (12) was found mainly on stumps and dying parts at the base of living trees, with a diameter of more than 20 cm, in contrast to *Exidiopsis calcea* (11) – on broken wood lying on the ground with a diameter of 10-20 cm, in various stages of decomposition. The sporocarps of *Mycena galericulata* (8) and the representatives of the genus *Pluteus* (with a total of 12 finds) were found mainly on stumps with broken wood structure, without bark or on fallen biomass. *Fomes fomentarius* (16) and *Trichaptum biforme* (6) were found on wood in the initial stages of decomposition, with a diameter of more than 20 cm, the latter being only on wood lying on the ground, and *F. fomentarius* – on live, standing dead and fallen stems. Only two of the observed basidiomycetes – *Stereum hirsutum* (49) and *Exidiopsis calcea* (11) – were found in all 4 sample areas. *Fomes fomentarius* (16), *Trichaptum biforme* (6), *Polyporus varius* (Pers.) Fr. (4) and *Calocera cornea* (Batsch) Fr. (4) were found in three sample ares. Most species were found in only one or two sample areas, incl. two of the species with a greater number of finds – *Schizophyllum commune* (9) and *Pluteus cervinus* (7) – found in only one sample area.

Table 5. Species composition of fungi associated with dead beech wood
Number of findings (F); Sample areas (SA № according Table 1)

Species	F	SA	Species	F	SA
BASIDIOMYCOTA					
Amaropostia stiptica (Pers.) Cui, Shen & Dai	**2**	1	*Mucidula mucida* (Schrad.) Pat.	**3**	1,3
Armillaria (Fr.) Staude (rhizomorphs)	**2**	3,4	*Mucronella flava* Corner	**1**	1
Bjerkandera adusta (Willd.) P. Karst.	**3**	1,3	*Mycena galericulata* (Scop.) Gray	**8**	1,2
Bjerkandera fumosa (Pers.) P. Karst.	**1**	1	*Mycena haematopus* (Pers.) P. Kumm.	**2**	1
Calocera cornea (Batsch) Fr.	**4**	1,3,4	*Mycena inclinata* (Fr.) Quél	**1**	2
Cerioporus varius (Pers.) Zmitr. & Kovalenko	**4**	1,3,4	*Mycoacia livida* (Pers.) Zmitr.	**5**	3,4
Cerrena unicolor (Bull.) Murrill	**2**	3	*Neoantrodia serialis* (Fr.) Audet	**1**	1
Coprinellus micaceus (Bull.) Vilg.,Hop. & J. John.	**1**	3	*Neolentinus cyathiformis* (Sch.)D.Magg.&Trass.	**2**	1,4
Cortinarius (Pers.) Gray	**1**	1	*Peniophora incarnata* (Pers.) P. Karst.	**2**	2
Crepidotus applanatus (Pers.) P. Kumm.	**1**	3	*Pholiota squarrosa* (Vahl) P. Kumm.	**1**	1
Crepidotus mollis (Schaeff.) Staude	**1**	1	*Plicaturopsis crispa* (Pers.) D.A. Reid	**2**	4
Crucibulum leave (Huds.) Kambly	**1**	3	*Pluteus cervinus* (Schaeff.) P. Kumm.	**7**	1
Cyanosporus caesius (Schrad.) McGinty	**3**	1	*Pluteus cinereofuscus* J.E. Lange	**4**	1,2
Cyathus striatus Willd.	**2**	3	*Pluteus fenzlii* (Schulzer) Corriol & Moreau	**1**	4
Dacrymyces stillatus Nees	**2**	1,3	*Porostereum spadiceum* (Pers.) Hjort. & Ryv.	**2**	3,4
Exidia glandulosa (Bull.) Fr.	**1**	1	*Psathyrella tephrophylla* (Romagn.) Bon	**1**	1
Exidiopsis calcea (Pers.) K. Wells	**11**	1,2,3,4	*Pycnoporus cinnabarinus* (Jacq.) P. Karst.	**2**	1,2
Flammulaster limulatus (Fr.) Watling	**1**	1	*Radulomyces confluens* (Fr.) M.P. Christ.	**3**	1
Flavidoporia mellita (Niemelä & Penttilä) Audet	**1**	4	*Sarcodontia spumea* (Sowerby) Spirin	**1**	3
Fomes fomentarius (L.) Fr.	**16**	1,3,4	*Schizophyllum amplum* (Lév.) Nakasone	**1**	1
Galerina marginata (Batsch) Kühner	**4**	1	*Schizophyllum commune* Fr.	**9**	2
Ganoderma adspersum (Schulzer) Don	**1**	1	*Scytinostroma hemidichophyticum* Pouzar	**1**	1
Gloeoporus pannocinctus (Romell) J. Erikss.	**1**	1	*Steccherinum fimbriatum*	**1**	1
Gymnopilus penetrans (Fr.) Murrill	**1**	1	*Stereum hirsutum* (Willd.) Pers.	**49**	1,2,3,4
Gymnopus (Pers.) Roussel	**1**	1	*Stereum rugosum* Pers.	**12**	1,4
Gymnopus androsaceus (L.) D. Magg. & Trass.	**1**	1	*Stereum subtomentosum* (Pers.) J. Erikss.	**5**	2,3
Gymnopus confluens (Pers.) Ant.,Hall.&Noord.	**1**	1	*Stropharia caerulea* Kreisel	**2**	3,4
Hericium cirrhatum (Pers.) Nikol.	**1**	1	*Trametes gibbosa* (Pers.) Fr.	**1**	1
Hydnoporia tabacina (Sow.) Spirin,Miett.&Lar.	**1**	1	*Trametes hirsuta* (Wulfen) Lloyd	**11**	1,2
Hypholoma fasciculare (Huds.) P. Kumm.	**1**	1	*Trametes ochracea* (Pers.) Gilb. & Ryvarden	**1**	1
Hypholoma lateritium (Schaeff.) P. Kumm.	**3**	1	*Trametes pubescens* (Schumach.) Pilát	**1**	1
Inocybe curvipes P. Karst.	**1**	1	*Trametes suaveolens* (L.) Fr.	**2**	1,2
Inocybe geophylla P. Kumm.	**2**	1	*Trametes versicolor* (L.) Lloyd	**10**	2,3
Lentinus brumalis (Pers.) Zmitr.	**1**	1	*Trametopsis cervina* (Schwein.) Tomšovský	**1**	3
Lycoperdon perlatum Pers.	**4**	1,4	*Trichaptum biforme* (Fr.) Ryvarden	**6**	1,2,3
Megacollybia platyphylla (Pers.) Kotl. & Pouzar	**2**	1	*Tubaria furfuracea* (Pers.) Gillet	**1**	1
Meripilus giganteus (Pers.) P. Karst.	**1**	1	*Vuilleminia comedens* (Nees) Maire	**1**	2
Mycetinis alliaceus (Jacq.) Earle ex Wil. & Des.	**2**	1,2	*Xylodon flaviporus* (B.&Curt.ex Cooke)R.&Lan.	**1**	1
ASCOMYCOTA					
Biscogniauxia nummularia (Bull.) Kuntze	**9**	1,2,4	*Hypoxylon fuscum* (Pers.) Fr.	**2**	1
Calycina citrina (Hedw.) Gray	**17**	1,3,4	*Jackrogersella multiformis* (Fr.)Wen.,Kuh.&Stad.	**5**	1
Chaetosphaerella phaeostroma(D.&Mon.)Müll.&B.	**1**	1	*Jackrogersella cohaerens* (Pers.)Wen.,Kuh.&Stad.	**11**	1,2,3,4
Chlorociboria aeruginascens (Nyl.) Kanouse	**3**	1	*Kretzschmaria deusta* (Hoffm.) P.M.D. Martin	**7**	1
Daldinia concentrica (Bolton) Ces. & De Not.	**3**	1	*Mollisia cinerea* (Batsch) P. Karst.	**1**	1
Diatrype disciformis (Hoffm.) Fr.	**20**	1,2,3,4	*Neobulgaria pura*	**2**	1,3
Diatrype stigma (Hoffm.) Fr.	**7**	2,3	*Neonectria coccinea* (Pers.) Rossman & Samuels	**1**	1,4
Hypocrea rufa (Pers.) Fr.	**1**	1	*Xylaria hypoxylon* (L.) Grev.	**24**	1,3,4
Hypoxylon fragiforme (Pers.) J. Kickx	**31**	2,3,4	*Xylaria polymorpha* (Pers.) Grev.	**1**	1
MYXOMYCOTA					
Ceratiomyxa fruticulosa T. Macbr.	**3**	1,2	*Physarum* Pers.	**3**	1
Badhamia foliicola Lister	**1**	1	*Stemonitis axifera* (Bull.) T. Macbr.	**1**	1
Cribraria argillacea (Pers. ex J.F. Gmel.) Pers.	**1**	2	*Trichia decipiens* (Pers.) T. Macbr.	**4**	1
Fuligo septica (L.) F.H. Wigg.	**1**	1	*Trichia varia* (Pers. ex J.F. Gmel.) Pers.	**1**	4
Lycogala epidendrum (J.C. Buxb. ex L.) Fr.	**1**	1	*Tubifera ferruginosa* (Batsch) J.F. Gmel.	**2**	1

Table 6. Number of species from the different taxonomic groups, according to their occurrence during the survey.

Sample areas	SA №	Findings Division	Occurrence (number of species)					Total number of findings	Average number of finds per species
			single	moderately (2-4)	frequently (5-10)	en masse (>10)	Total		
Petrohan	1	Basidiomycota	39	12	5	0	**56**	111	1.9
		Ascomycota	6	6	2	1	**15**	59	3.9
		Myxomycota	5	3	0	0	**8**	14	1.8
		All	**50**	**21**	**7**	**1**	**79**	**184**	**2.3**
Barzia	2	Basidiomycota	6	5	4	0	**15**	57	3.8
		Ascomycota	0	3	1	1	**5**	34	6.8
		Myxomycota	1	1	0	0	**2**	3	1.5
		All	**7**	**9**	**5**	**1**	**22**	**94**	**4.3**
Tihia kat	3	Basidiomycota	13	7	1	1	**22**	60	2.7
		Ascomycota	1	3	3	0	**7**	36	5.2
		Myxomycota	0	0	0	0	**0**	0	0
		All	**14**	**10**	**4**	**1**	**29**	**96**	**3.3**
Zlatni mostove	4	Basidiomycota	10	4	1	0	**15**	26	1.7
		Ascomycota	3	5	0	0	**8**	17	2.1
		Myxomycota	1	0	0	0	**1**	1	1
		All	**14**	**9**	**1**	**0**	**24**	**44**	**1.8**
Total		Basidiomycota	38	26	7	5	**76**	**254**	**3.3**
		Ascomycota	5	4	4	5	**18**	**146**	**8.1**
		Myxomycota	6	4	0	0	**10**	**18**	**1.8**
		All	**49**	**34**	**11**	**10**	**104**	**418**	**4**

Among division Ascomycota, 18 species were identified with 146 finds. Their average occurrence is the highest – 8.1 finds per species (Table 5). The number of finds of the species is evenly distributed by occurrence. The most common of the ascomycetes is *Hypoxylon fragiforme* (Pers.) J. Kickx (with 31 occurrences), followed by *Xylaria hypoxylon* (L.) Grev. (24), *Diatrype disciformis* (Hoffm.) Fr. (20), *Bisporella citrina* (Batsch) Korf & S.E. Carp. (17), *Jackrogersella cohaerens* (Pers.) L.Wendt, Kuhnert & M. Stadler (11), *Biscogniauxia nummularia* (Bull.) Kuntze (9), *D. stigma* (Hoffm.) Fr. (7), *Kretzschmaria deusta* (Hoffm.) P.M.D. Martin (7) and *J. multiformis* L. Wendt, Kuhnert & M. Stadler (5). The other 9 species were found with 1-3 finds.

Most ascomycetes were found on broken wood of different sizes and in different stages of decomposition lying on the ground. The most common representatives of the genera *Hypoxylon*, *Jackrogersella*, *Biscogniauxia* and *Diatrype* develop en masse on recently felled hardwood with bark, i.e. they are mainly associated with the initial stages of wood decomposition, while *Xylaria hypoxylon*, *Kretzschmaria deusta* and *Bisporella citrina* develop mainly on wood in a more advanced stage of decomposition. The remaining species are more broadly specialized. Only *Diatrype disciformis* and *Jackrogersella cohaerens* were found in all 4 surveyed sample areas, *Hypoxylon fragiforme*, *Biscogniauxia nummularia*, *Xylaria hypoxylon* and *Bisporella citrina* – in three SA, and the rest – in one or two SA.

There were 10 species from the division Myxomycota, and 18 finds in total. They were found to have the lowest occurrence of 1-2 finds - an average of 1.8 per species. Of the myxomycetes with 4 findings is only *Trichia decipiens* (Pers.) T. Macbr., with 3 each – *Ceratiomyxa fruticulosa* Micheli and *Physarum* sp. Almost all the finds are on wood lying on the ground or stumps of long-cut trees, with a diameter of more than 10 cm and in an advanced stage of decomposition. In the Petrohan SA, 8 species of myxomycetes were identified with 14 of the 18 finds, and only 3 species – in Barzia SA (with 3 finds) and Zlatni mostove SA (1).

The data on the distribution of the identified fungal species according to the condition, stage of decay and size of the wood are summarized in

Table 7. In total, only 15 findings of 8 fungal species were found on living trees or on their dying parts for all the surveyed sites: *Fomes fomentarius* (with 2 finds), *Mucidula mucida* (Schrad.) Höhn. (1), *Nectria coccinea* Desm. (1) – on still alive, wounded or broken and partially fallen stems, *Kretzschmaria deusta* (2), *Stereum rugosum* (6), *Radulomyces confluens* (Fr.) M.P. Christ. (1), *Mycena galericulata* (1), *Gymnopus* sp. (1) – on wood in an advanced stage of decay at the base of a live stem. All of the remaining 403 finds were of dead wood in various stages of decay.

Most often wood-destroying fungi (with 306 of the findings) were found on wood lying on the ground, broken by wet snow and strong wind. The largest number of finds are on wood with a diameter of more than 20 cm (162) and in the range of 10-20 cm (108). There is no significant difference in the number of finds, depending on the stage of decomposition of the wood - in all degrees it varies from 96 to 110.

Table 7. Distribution of the identified fungal species according to the condition, stage of decay and size of the wood.

	Fine debris	Stump	Condition				Stage of decay				Diameter				**Total**
degree			1	2	3	4	1	2	3	4	1	2	3	4	
Basidiomycota															
species	9	20	4	4	8	60	21	17	39	37	6	19	46	37	76
findings	13	33	12	8	12	176	66	58	65	65	11	56	78	106	254
Ascomycota															
species	0	4	2	1	2	17	11	9	11	11	4	8	12	11	18
findings	0	22	3	1	3	117	42	37	33	35	20	38	42	47	146
Myxomycota															
species	1	4	0	0	0	8	2	1	3	7	1	0	4	7	10
findings	1	5	0	0	0	13	2	1	6	9	1	0	8	9	18
Total															
species	**10**	**28**	**6**	**5**	**10**	**85**	**34**	**27**	**53**	**55**	**11**	**27**	**62**	**55**	**104**
findings	**14**	**66**	**15**	**9**	**15**	**306**	**110**	**96**	**104**	**109**	**32**	**94**	**128**	**162**	**418**

Fig. 1 and Fig. 2 illustrates the general occurrence of fungal species associated with dead beech wood in the Stara Planina and Vitosha Mountains. It shows that in both mountains the representatives of division Basidiomycota are the most common, but most of them are found singly or with 2-4 finds. The number of species is significantly greater in Stara Planina. Ascomycetes were found with a constant total number of finds (1-10) in each of the two mountains, but their occurrence is also greater in Stara Planina, where almost all myxomycetes were also found.

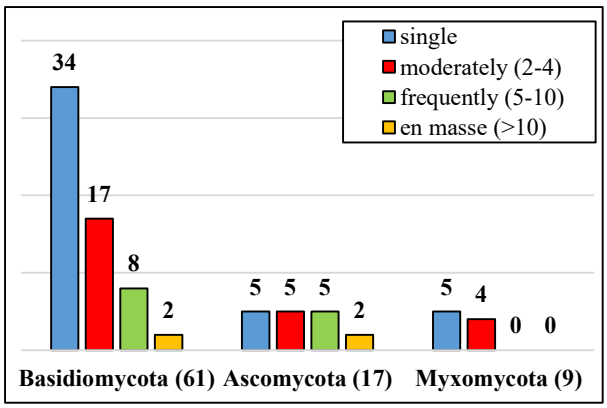

Fig. 1. Number of fungi species from the taxonomic groups identified in St. Planina Mt.

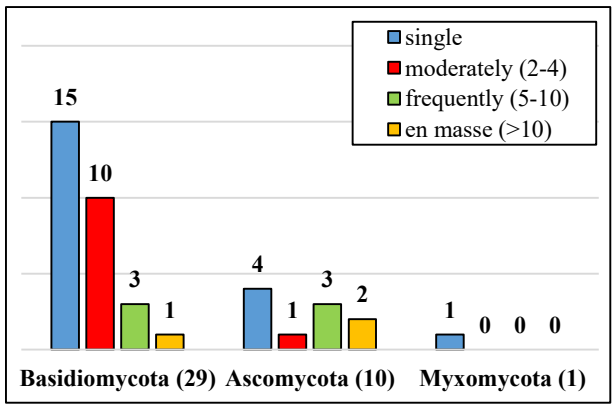

Fig. 2. Number of fungi species from the taxonomic groups identified in Vitosha Mt.

Discussion

The obtained data convincingly prove that the species diversity of wood-destroying fungi depends primarily on the presence of more wood in different stages of decomposition. This is confirmed by the 79 species of fungi found in the sample area Petrohan. This stand is 120 years old and is located at the highest altitude (1500 m a.s.l.). It is periodically affected by various abiotic, biotic and anthropogenic factors, which led to the episodic death of trees or their parts and the presence of a variety of wood of different sizes and in different stages of decomposition. Analysis of the quantitative and qualitative structure of dead standing trees and large woody debris, as well as the occurrence of associated macromycetes in beech stands in Poland (Kacprzyk et al., 2014) shows that altitude has a significant effect on the amount and structure of dead wood in forest stands. When approaching the upper forest limit, the thickness of large woody debris decreases and the proportion of dead standing trees increases. This differs from the largest proportion of lying large-sized dead wood found in the Petrohan sample area (Table 4).

The second surveyed beech stand in Stara Planina, in which the SA Barzia was laid, is the oldest (130 years), but is located at the lowest altitude (650 m a.s.l.). Fewest species of fungi were identified in this sample area (22). There is a lot of dead wood in it, due to massive abiotic damage (wet snow and strong wind) in the previous year, but the main part of it is standing and still in the initial stage of decomposition. At this stage, representatives of the division Ascomycota settle en masse on the wood, which in this case are only 5 species, but are found on all fallen and broken trees and are described with the largest number of finds - 34 or an average of 6.8 finds per species. The most widespread of these species are *Hypoxylon fragiforme* (18 finds) and *Biscogniauxia nummularia* (7). The finds are on hard wood with bark or with partially fallen bark, which was relatively recently broken and fallen to the ground. This explains the relatively large number of finds (94) in this sample area. A similar conclusion was drawn by Lepinay et al. (2021) who found that in young (recently dead) deadwood, fungi were generally less abundant, less diverse and less active than in older deadwood.

Almost the same number of species (24), but with significantly fewer finds (44), was also found in the SA Zlatni mostove (Vitosha), where the limiting factor is the small amount of dead wood. The difference in the altitudes of the trial areas laid out in Vitosha is smaller - SA Tihia kat is in a 90-year-old beech stand at 1100 m above sea level, and SA Zlatni mostove - in a 110-year-old beech forest at 1400 m. SA Tihia kat is in mixed stand with participation of beech (7), aspen (3) and single oak, hornbeam and sycamore. In this sample area, the amount of dead wood is not small, but some of it is not beech. This explains the relatively small number of species of fungi found on beech wood - 29 species with a total of 96 finds.

Fungal species diversity is closely related to deadwood quality (Kacprzyk et al., 2014), with most fungal taxa being recorded on coarse woody debris and on dead standing trees in an advanced stage of decay. According to Hoppe et al. (2015) fungal richness on beech deadwood tended to increase as decay progressed, and fruiting body abundance was highest at intermediate stages of decay, i.e. fungal communities most strongly depend on the specifics of dead wood, regardless of habitat features. The number of species per tree in beech increased significantly with increasing tree size, indicating that large trees are most valuable for fungal diversity (Heilmann-Clausen & Christensen, 2004). Small trees and branches host more species per unit volume than larger trees and logs, while standing dead trees are the poorest in species.

The relatively even distribution of the number of ascomycete species and their findings by stages of wood decay is noticeable, which testifies to their constant presence and participation in all stages of the decomposition of dead wood. Their significance is particularly important for the degradation of small-sized wood, with a diameter of up to 10 cm.

The number of species of wood-destroying fungi from the division Basidiomycota on wood in the initial stages of decay is significantly lower, compared to wood in an advanced stage of decomposition, but they are also found with the same total number of findings in all stages of decomposition. Often basidiomycetes, described on thin branches with a diameter of less than 5 cm, develop en masse on plant residues (fall),

and are not necessarily associated with wood (such as *Coprinellus micaceus* (Bull.:Fr.) Vilgalys, Hopple & Jacq.Johnson).

The species of the Myxomycota division develop mainly on wood in advanced stages of decay. It can be assumed that their actual number is higher, but they have not been found, due to the small size of the spore-bearing structures in most myxomycetes or their possible presence in the plasmodial stage.

Conclusions

Altitude is not a leading factor in the species diversity of wood-destroying fungi, which depends primarily on the presence of more wood in different stages of decomposition. In the initial stages of wood decomposition, few species of fungi develop, mainly representatives of the division Ascomycota. Ascomycetes participate in all stages of the decomposition of dead wood, and their importance is particularly important for the decomposition of small wood, up to 10 cm in diameter. The number of species of wood-destroying fungi from the division Basidiomycota on wood in the initial stages of decay is significantly lower, compared to wood in an advanced stage of decomposition. The species of the Myxomycota division develop mainly on wood in advanced stages of decay.

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References

Bače, R., Svoboda, M., & Vítková, L. (2019). *Deadwood management in production forests. Management guidelines for forest managers in Central European temperate forests*. Prague, Czech Republic: Czech University of Life Sciences.

Copoț, O., Mardari, C., Bîrsan, C.C., & Tănase, C. (2020). Lignicolous fungal assemblages and relationships with environment in broad-leaved and mixed forests from the North-East Region of Romania. *Plant Ecology and Evolution*, 153(1), 45-58. doi: 10.5091/plecevo.2020.1688.

Floren, A., Krüger, D., Müller, T., Dittrich, M., Rudloff, R., Hoppe, B., & Linsenmair, K. (2015). Diversity and Interactions of Wood-Inhabiting Fungi and Beetles after Deadwood Enrichment. *PLoS ONE*, 10(11), e0143566. doi: 10.1371/journal.pone.0143566.

Fukasawa, Y. (2021). Ecological impacts of fungal wood decay types: A review of current knowledge and future research directions. *Ecological Research*, 36, 910-931. doi: 10.1111/1440-1703.12260

Garnweidner, E. (1996). *Mushrooms and Toadstools of Britain & Europe*, Colins Nature Guide. HarperColinsPublishers, 256 p.

Heilmann-Clausen, J., & Christensen, M. (2004). Does size matter? On the importance of various dead wood fractions for fungal diversity in Danish beech forests. *Forest Ecology and Management*, 201, 105-117. doi: 10.1016/j.foreco.2004.07.010

Hoppe, B., Purahong, W., Wubet, T., Kahl, T., Bauhus, J., Arnstadt, T., Hofrichter, M., Buscot, F., & Krüger, D. (2015). Linking molecular deadwood-inhabiting fungal diversity and community dynamics to ecosystem functions and processes in Central European forests. *Fungal Diversity*, 77, 367-379. doi: 10.1007/s13225-015-0341-x.

Janssen, P. (2004). *All about mushrooms*. Saint Petersburg, 160. (In Russian)

Kacprzyk, M., Bednarz, B., & Kuźnik E. (2014). Dead Trees in Beech Stands of the Bieszczady National Park: Quantitative and Qualitative Structure of Associated Macrofungi. *Applied Ecology and Environmental Research*, 12(2), 325-344.

Lamaison, J.L., & Polese, J.M. (2005). *The Great Encyclopedia of Mushrooms*. Könemann, 240 p.

Lazarov, S., Dimova, D., & Lazarova, S. (2012). *Inventory and management of deadwood in forest ecosystems*. Sofia, Bulgaria: Geosoft Ltd. (In Bulgarian).

Lepinay, C., Jiráska, L., Tláskal, V., Brabcová, V., Vrška, T., & Baldrian, P. (2021). Successional Development of Fungal Communities Associated with Decomposing Deadwood in a Natural Mixed Temperate Forest. *Journal of Fungi*, 7, 412. doi: 10.3390/jof7060412

Lonsdale, D., Pautasso, M., & Holdenrieder, O. (2008). Wood-decaying fungi in the forest: conservation needs and management options. *European Journal of Forest Research*, 127, 1-22. doi: 10.1007/s10342-007-0182-6.

Marcot, B.G. (2017). *A Review of the Role of Fungi in Wood Decay of Forest Ecosystems*. Research note PNW-RN-575. Portland, USA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Ódor, P., Heilmann-Clausen, J., Christensen, M., Aude, E., van Dort, K.W., Piltaver, A., Siller, I., Veerkamp, M.T., Walleyn, R., Standovár, T., van Hees, A.F.M., Kosec, J., Matocec, N., Kraigher, H., & Grebenc, T. (2006). Diversity of dead wood inhabiting fungi and bryophytes in semi-natural beech forests in Europe. *Biological Conservation*, 131, 58-71. doi: 10.1016/j.biocon.2006.02.004

Poryazov, Y., Tonchev, T., & Dobrichov, I. (2004). *Handbook of foresty measurments*. Sofia, Bulgaria: Bulvark. (In Bulgarian).

Stancheva, Y., Bencheva, S., Pavlidis, T., & Ilieva, M. (2009). *Atlas of Wood Decaying Fungi*. Sofia-Moscow, Ppb, 349 pp.

Tláskal, V., Brabcová, V., Vetrovský, T., Jomura, M., López-Mondéjar, R., Oliveira Monteiro, L.M., Saraiva, J.P., Human, Z.R., Cajthaml, T., Nunes da Rocha, U., & Baldrian, P. (2021). Complementary roles of wood-inhabiting fungi and bacteria facilitate deadwood decomposition. *mSystems*, 6, e01078-20. doi: 10.1128/msystems.01078-20

Tong, L., Lizhen, C., Xiufang, S., Xiaoyong, C., Yulian, W., Li, T., Yanhong, M., & Zhihong, X. (2022). Wood decay fungi: an analysis of worldwide research. *Journal of Soils and Sediments*, 22, 1688-1702. doi: 10.1007/s11368-022-03225-9

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