DOI: 10.1515/frp-2016-0028
Available online: www.lesne-prace-badawcze.pl

Leśne Prace Badawcze / *Forest Research Papers*
Wrzesień / September 2016, Vol. 77 (3): 261–275

ORIGINAL RESEARCH ARTICLE

e-ISSN 2082-8926

Communities of fungi in decomposed wood of oak and pine

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Abstract. The abundance and diversity of wood decomposing fungi were investigated by isolating and cultivating filamentous fungi from wood and by detection of fruit bodies of ascomycetous and basidiomycetous fungi. The objective was to study the impact of forest management on fungi in 100-year-old oak and 87-year-old Scots pine forests in Northern Poland. Fungi were found on coarse woody debris of decayed stumps and fallen logs, boughs and branches in each of the three (managed and unmanaged) examined stands. In total, 226 species of Oomycota and fungi were recorded. Oak wood was colonized by one species of Oomycota and 141 species of fungi including Zygomycota (19 species), Ascomycota (103 species) and Basidiomycota (19 species). Scots pine wood was also colonized by one species of Oomycota and 138 species of fungi including Zygomycota (19 species), Ascomycota (90 species) and Basidiomycota (29 species). In the first, second and third stages of decomposition, the oak wood was colonized by 101, 89 and 56 species of fungi respectively and pine wood was colonized by 82, 103 and 47 species respectively. Eighty three of the observed species (37%) occurred on both types of wood, while the other species displayed nutritional preferences. A decrease in the number of species with advancing decay indicates the necessity for a continuous supply of dead wood to the forest ecosystem.

This supply would secure the continuity of fauna and flora and guarantee a stable forest development. The nutritional and ecological preferences of many fungal species furthermore indicate the necessity of supplying the forests with wood of different species.

In commercially managed forests the results obtained here will aid in: (i) the development of strategies for effective dead wood management in the context of forest productivity and future wood stock growth, as well as (ii) finding a compromise between forest management requirements and environmental protection.

Keywords: communities of fungi, oak, Scots pine, succession, wood decomposition

1. Introduction

Dead wood is presently considered to be a crucial element of forest ecosystems. The inventory of dead wood resources on permanent observation plots (POP) showed that the amount of dead wood substance (stocks after cut-down trees, standing and down trees with diameter over 10 cm) in polish woods amounts to 0–298 m³/ha (Czerepko et al. 2008). The largest resources were found in diversified, in terms of age and species, forest stands of Carpathian beech forest and multispecies fertile oak-hornbeam forest in strict reserve of the Białowieża National Park. The smallest resources, on the other hand, were found in young pine forest stands. The amount that provides conditions for essential diversity of destruents ranges from 50–200 m³/ha. The amount depends on the type of the forest (Buchholz et al. 1993; Byk, Mokrzycki 2007).

Protection of biodiversity requires leaving the deadwood in forest in different stages of decomposition (Forest Protection Guidelines).

Maintaining microorganisms' biodiversity in forestry is necessary. It leads to a competition that eliminates mono-

Submitted: 20.04.2016, reviewed: 4.05.2016, accepted after revision: 17.07.2016

culture, that is, absolute domination of single organisms, including plants' pathogens, and determines the durability and harmony of natural ecosystems (Gutowski et al. 2004).

The main colonizers of wood are fungi due to their cellulolytic characteristics (Rayner, Boddy 1988). Fungi decompose wood causing white, brown or soft-rot. The type of rot depends on the degree of decomposition of cellulose, hemicellulose and lignin, as well as on the enzymatic properties of colonizers. The decomposition of beech, Douglas-fir and pine wood caused by fungi was examined by Savory (1954), Seifert (1983), Crawford et al. (1990), Worrall et al. (1997), Harju et al. (2001), Venalainen et al. (2003) and Fukasawa et al. (2005, 2009).

Purpose of this research was to learn:

- the possibilities of natural colonization of dead wood by fungi from surroundings,
- the structure and succession of mycobionts colonizing the wood of oak and pine, and
- nutritional preferences of fungi.

The goals listed above in economic forests allow for the development of effective guidelines for managing dead wood resources in the context of target volume and reaching a compromise between forest management and nature protection. The practice of forestry should answer all the functions of forest, while preserving environments for saproxylic and saprotrophic organisms' development.

2. Materials and methods

The research material was samples from stocks (upper ring of 10 cm), logs and branches (20–30 cm wide), collected one -time in August of 2014, each time on 2.8 ha area from: (i) 100 year-old forest stands of reserve's common oak (*Quercus robur* L.) from Drawa National Park (53.08 N 15.27 E; seven samples from logs and six from branches; six, four and three samples were characterized by 1, 2 and 3 degrees of wood decompositions respectively, according to a 5-step scale similar to Hunter's scale (1990), (ii) 100 year-old economy forest stand of common oak from Smolarz forest inspectorate (52.83 N, 15.83 E; eleven samples from stocks and four from branches; eight, five and two samples were characterized by 1, 2 and 3 degree of wood decomposition, respectively), and from a 87-year-old pine forest stand (*Pinus sylvestris* L.) from Torzym forest inspectorate (52.31 N, 15.08 E; nine samples from stocks from economy forest stands, four from logs and three from branches; four samples from stocks from reserve's forest stands were collected were four samples from stocks, ten samples from logs and four from branches; twelve, sixteen and six samples were characterized by 1, 2 and 3 degree of decomposition, respectively). Drawa National Park, Smolarz and Torzym forest inspectorates' forest stands were chosen for the research to recognize the communities of fungi in reserve and economic forest stands.

In the first degree of decomposition (after 1–3 years), the wood was healthy with unchanged structure and colour. After 5–20 years, bark and around 30% of wood showed symptoms of decay and decomposition in the second degree of decomposition. In third degree (after 20–30 years), more than 30% of wood showed symptoms of decomposition and the bark was completely reduced.

The day after collecting samples, 36 inocula (5-10 cm long) from each sample were placed on PDA (39 g l−1 Difco PDA, pH 5.5) and SNA (1 g l−1 KH2PO4, 1 g l^{-1} KNO_3, 0.5 g l^{-1} $MgSO_4$ x $7H_2O$, 0.5 g l^{-1} KCL, 0.2 g l^{-1} glucose, 0.2 g l^{-1} sucrose, 20 g l^{-1} agar) nutrients. Isolation was made from 1008 inocula of oak and 1224 inocula of pine. The fungi were marked on the base of morphology of the colony and sporulation that occurred on nutrients (Domsch et al. 1980; Seifert et al. 2011). Fungi fruiting on wood were identified on the base of the morphology of fruiting body. The degree of colonization of sample by the given taxon was expressed by the percentage of colonized inocula (filamentous fungi) or samples (fungi fruiting on wood).

3. Results

The wood of oak and pine was colonized by 226 taxa of Oomycota and Fungi (Table 1). Oak wood was colonized with one species of Oomycota and 141 species represented by Zygomycota (19 species), Ascomycota (103 species) and Basidiomycota (19 species). Pine wood was colonized by one species of Oomycota and 138 species of fungi represented by Zygomycota (19 species), Ascomycota (90 species) and Basidiomycota (29 species). In the first, second and third stage of decomposition, oak wood was colonized by 101, 89 and 56 species of fungi, and pine wood by 82, 103 and 47 species of fungi. Eighty-three species (37%) of fungi were present both on oak and pine wood. For the remaining, the fungi stated was nutritional specialization. On wood, in first and second degree of decomposition, stated was 20 and 16 taxa in oak wood.

4. Discussion

Dead wood is a part of circulation of matter and a natural environment for many organisms, including saproxylic and saprotrophic fungi. Matter from dead wood returns to circulation thanks to destruents and connected with them nutrient relations. The role of fungi in the process of decomposition is significant. They produce ectoenzymes allowing for decomposition of lignificated tissues. Lignin is generally unattainable for other destruents. A part of the species of fungi is related with specific species of forest trees.

It has been stated that there were 141 and 138 species of fungi on wood of oak and pine. The number of species was higher than 96 on wood of beech, which were stated by Fukasawa et al. (2009). Oak and pine wood, like beech wood, was colonized mainly by fungi from Zygomycota and Ascomycota class. According to Gutowski et al. (2004), Ascomycota colonize the wood of coniferous trees less frequently than deciduous trees. Results from our research confirm these observations; stated was 103 and 90 species of Ascomycota on wood of oak and pine.

Zygomycota, Ascomycota and Basidiomycota grew satisfactorily on used synthetic nutrient. Not highly selective glucose-potato (PDA) nutrient allowed for obtaining colonies that stood out with the pace of growth, structure and colour. SNA nutrient stimulated sporulation of Zygomycota and Ascomycota, allowing for fungi identification. Majority of Basidiomycota does not sporulate and fructify, not only on used PDA and SNA but also on other synthetic nutrients. That results in relatively high percentage of 'other Basidiomycota' marked on the base of presence of fibula in mycelium (Table 1). Large presence of *Penicillium* spp. only partly indicated from their nutritional preferences and ecological specialization. Fungi from *Penicillium* genus sporulate profusely. Numerous, small and light spores easily transported in nature by wind, water and insects allow for their common spread what results in their frequent detection. Omnipresence of *Penicillium* spp. in connection with their cellulolytic properties (Nilsson 1973, 1974; Poszytek 2016) leads to conjecture about their significant role in the process of wood decomposition.

Zygomycota and Ascomycota cause wood's soft rot. In nature, this process runs due to alternate wet and dry seasons, and at high and changeable absolute wood humidity (40–220%). Decomposition runs quite slow and is limited only to surface layers of wood (2–4 mm) attacked in the period of higher humidity. During drought, the decomposed wood crumbles, giving access to mycelium to colonize in the deeper layers, which leads to decomposed during the next damp season. Fungi colonize mainly on the exposed layers of wood due to lower concentration of carbon monoxide (Eaton, Hale 1993). Due to the influence of climate for many years, the decomposition and decay of wood reaches a considerable size.

It is claimed that fungi that cause soft rot belong to secondary colonizers, present at the final stages of decomposition (Fukasawa et al. 2011). Our research showed that Ascomycota occurred in the earlier stages of wood decomposition. Gradually, in the case of oak, the number of species decreased, and in the case of pine, it increased and then decreased. The reduced number of species promoted the increase of degree of colonization by single, dominant species, inter alia *Chaetosphaeria vermicularioides, Mucor* spp., *Mariannaea elegans*, *Penicillium* spp., *Sporothrix schenckii* and *Trichoderma* spp. Partly, these observations are consistent with Fukasawa et al. (2009) report. They also stated increase and then decrease in the number of species and degree of colonization of beech wood with progressive decomposition.

The number of species and the degree of colonization are negatively correlated with cellulose, hemicellulose and lignin contents in wood (Fukasawa et al. 2009). The drop in diversity of fungi in final stages of wood decomposition, beside lack of adequate food, may also be caused by competition and dominance of certain species. Fast growing species (e.g., species from *Absidia, Mortierella*, *Mucor* genus) effective in competing over substrate and living-space, and antagonistic species (among other species from *Penicillium*, *Trichoderma* genus) with the ability of antibiosis and parasitism may eliminate many earlier colonizers (Galgóczy et al. 2005). Slow-growing species, like *Ch. vermicularioides, M. elegans, S. schenckii,* which occur more frequently on strongly decomposed wood, are probably not very competitive in gaining living-space but effective in using secondary food nutrients. Their presence in antibiosis cannot be excluded.

Majority of identified Ascomycota species belonged to Dothideomycetes, Eurotiomycetes and Sordariomycetes. Therefore, it should be noticed that not only Xylariaceae decomposes wood (Rayner, Boddy 1988). Fungi from *Trichoderma* genus were the most numerous representatives of Sordariomycetes. *Trichoderma* spp. was less intensively colonized and did not decompose wood due to the lack of enzyme decomposing lignin, present in structures of early colonization (lamella of cells and outer cell wall) (Eaton, Hale 1993; Fukasawa et al. 2005). Before reaching cellulose, the fungi require earlier lignin decomposition by other fungi (Schwarze et al. 2000; Schmidt 2006). In earlier stages of decomposition, high interspecies diversity of *Trichoderma* was observed. In wood of pine, there were nine species present. In the later stage of decomposition, dominance of three of the most competitive species was visible: *T. harzianum*, *T. koningii* and *T. viride*. Last species was particularly numerous, despite that, accordingly to Fukasawa et al. (2011), it was a weaker destruent of wood. *Trichoderma viride* does not stop only at cellulose. It uses only a small percent of cellulose and supplements shortages in food through mycoparasitism (Dennis, Webster 1971; Kumar et al. 2010), which ensures its large presence.

Zygomycota are fast-growing fungi that sporulate numerously. They are oligotrophic to mesotrophic and thermos -tolerant. They do not have any ligninolytic or cellulolytic features (Nilsson 1973). They require earlier wood decomposition by other fungi. They belong to secondary species colonizing the substratum rich in simple carbohydrates (Hudson 1968; Osono, Takeda 2001). Increase in their frequency to 3 (in oak) and 2 (in pine) stadium of wood decomposition results from nutrition preferences and slower pace of oak wood decomposition. The wood contains tannins, which in contact with water or soil react with phosphates of iron that increases its durability and access for fungi.

During wood decomposition, fungi succession was observed. It was consistent with the scheme stated by Gutowski et al. (2004). Initially, according to Fukasawa et al. (2009), its course depended on physicochemical properties of wood (mainly density), enzymatic properties of fungi, ecological specialization and then on wood and nitrogen. Saprotrophs were present on each stage of decomposition. Initially, they were accompanied by plant parasites (optional and weak, e.g., species from genus *Alternaria*, *Botrytis*, *Cenangium, Ceratocystis*, *Cladosporium*, *Cylindro- carpon*, *Cytospora, Epicoccum, Fusarium, Gibberella, Nectria, Ophiostoma, Paraconiothyrium, Porodaedalea, Phoma*, *Pyrenochaeta*, *Sclerotinia, Sphaeropsis, Truncatella*). Communities of saprotrophs decomposing cellulose and using simple organic compounds in still fresh tissues (among others from genus *Acremonium, Chrysosporium, Humicola, Peniophora, Phialocephala, Phialophora, Phlebiopsis, Rhinocladiella*) in time become enriched by entomophagy (among others *Pochonia bulbilosa*) and there is an increase in the number of soil species (among others from genus *Penicillium* + *Talaromyces*, *Pseudogymnoascus*, *Sporothrix, Trichoderma*) (Nilsson 1973, 1974). Ascomycota from *Acremonium, Cadophora, Lecythophora, Oidiodendron, Phialophora* and *Phoma* genus, which are characterized by slow growth, were present first in initial two stages of oak and pine wood decomposition. *Mariannaea elegans* and *Myrmecridium schulzeri* were present in the third

Table 3. Percentage of inocula colonized by particular taxa

Taxa	Order, Class	Oak						Scots pine		
		Drawa National Park			Smolarz Forest District			Torzym Forest District		
		Wood decay rate								
		1	2	3	1	2	3	1	2	3
Oomycota										
Pythium sp.	Peronosporales, Incertae sedis	1.8	0.7						0.27	2.78
Zygomycota										
Absidia californica J.J. Ellis & Hesselt.[4] + *A. coerulea* Bainier [1,4] + *A. cylindrospora* Hagem[3] + *A. glauca* Hagem [1,3]	Mucorales, Incertae sedis,	12.9	1.0	50.0			1.4	1.11	2.21	1.85
Mortierella alpina Peyronel[2] + *M. bainieri* Costantin + *M. echinula* Linnem.+ *M. elongata* Linnem.[2] + *M. exigua* Linnem. +*M. gamsii* Milko + *M. humilis* Linnem. ex W. Gams[3] + *M. hyalina* (Harz) W. Gams [1] + *M. jenkinii* (A.L. Sm.) Naumov + *M. minutissima* Tiegh. + *M. parvispora* Linnem.[1] + *M. zonata* Linnem. ex W. Gams[3] + *M. verticillata* Linnem.[3] + *Mortierella* spp.	Mortierellales, Incertae sedis	10.6	1.4	51.7	2.8		20.7	2.76	13.95	10.17
Mucor hiemalis Wehmer[2] + *M. plumbeus* Bonord.+ *M. racemosus* Fresen[1,2] + *Mucor* sp.	Mucorales, Incertae sedis	1.2	7.0	20.0			16.7	1.38	15.99	36.1
Piptocephalis indica B.S. Mehrotra & Baijal	Zoopagales, Incertae sedis						4.1			
Umbelopsis isabellina (Oudem.) W. Gams[2] + *U. ramanniana* (Möller) W. Gams[4] + *U. vinacea* (Dixon-Stew.) Arx[1,2]	Mucorales, Incertae sedis	10.6	46.1	10.0	3.7		13.8	22.11	9.05	4.63

Taxa	Order, Class	Oak						Scots pine		
		Drawa National Park			Smolarz Forest District			Torzym Forest District		
		Wood decay rate								
		1	2	3	1	2	3	1	2	3
Ascomycota										
Aequabiliella effusa (Damm & Crous) Crous	Phaeomoniellales, Eurotiomycetes							4.86		
Acremonium charticola (Lindau) W. Gams [1,2] + *A. curvulum* W. Gams + *A. falciforme* (G. Carrión) W. Gams + *Acremonium* sp.[2]	Hypocreales, Sordariomycetes	13.0	14.5		9.3	13.9		17.63	10.08	
Alternaria alternata (Fr.) Keissl.[2] + *A. botrytis* (Preuss) Woudenberg & Crous[4] + *A. oudemansii* (E.G. Simmons) Woudenberg & Crous[3]	Pleosporales, Dothideomycetes	3.7	1.4		1.8			12.21	2.31	
Annulohypoxylon multiforme (Fr.) Y.M. Ju, J.D. Rogers & H.M. Hsieh	Xylariales, Sordariomycetes		4.04							
Aspergillus versicolor (Vuill.) Tirab.[1,3]	Eurotiales, Eurotiomycetes		0.7	15.0			13.8	1.11	1.38	
Beauveria bassiana (Bals.-Criv.) Vuill. [3]	Hypocreales, Sordariomycetes							0.55		
Bipolaris oryzae (Breda de Haan) Shoemaker[3]	Pleosporales, Dothideomycetes							1.11		
Botrytis cinerea Pers.[3]	Helotiales, Leotiomycetes							1.11		
Cadophora gregata (Allington & D.W. Chamb.) T.C. Harr. & McNew + *C. melinii* Nannf.[1,3]		22.4	8.3		23.1			5.55	0.92	
Camarosporium feurichii Henn.	Botryosphaeriales, Dothideomycetes	1.4								
Camposporium pellucidum (Grove) S. Hughes	Incertae sedis, Incertae sedis		0.7							
Candida sp.			0.3							
Cenangium ferruginosum Fr.	Helotiales, Leotiomycetes							4.7		
Ceratocystis coerulescens (Münch) B.K. Bakshi + *Ceratocystis* sp.[3]	Microascales, Sordariomycetes		3.5		5.5			1.11		
Cephalotrichum stemonitis (Pers.) Nees		1.0								

Taxa	Order, Class	Oak						Scots pine		
		Drawa National Park			Smolarz Forest District			Torzym Forest District		
		Wood decay rate								
		1	2	3	1	2	3	1	2	3
Chaetosphaeria vermicularioides (Sacc. & Roum.) W. Gams & Hol.-Jech.[1,2]	Chaetosphaeriales, Sordariomycetes	12.5	24.3	66.7	18.5	27.8	30.5		9.72	20.17
Chloridium cylindrosporum W. Gams & Hol.-Jech. [3] + *Ch. phaeophorum* (W. Gams) Réblová & W. Gams					4.6				9.25	
Chrysosporium merdarium (Ehrenb.) J.W. Carmich.	Onygenales, Eurotiomycetes	0.4								
Cladophialophora arxii Tintelnot [1,2,4] + *C. carrionii* (Trejos) de Hoog, Kwon-Chung & McGinnis	Chaetothyriales, Eurotiomycetes	7.4	7.9	10.0			50.0		4.16	4.62
Cladosporium cladosporioides (Fresen.) G.A. de Vries [2]+ *C. herbarum* (Pers.) Link[1] + *C. sphaerospermum* Penz.[3]	Capnodiales, Dothideomycetes	2.3	1.0	6.7		13.9		16.8	6.19	1.85
Clonostachys rosea (Link) Schroers, Samuels, Seifert & W. Gams[1]	Hypocreales, Sordariomycetes,	2.3		41.7			6.9		1.93	
Curvularia australiensis (Tsuda & Ueyama) Manamgoda, L. Cai & K.D. Hyde[4]	Pleosporales, Dothideomycetes								0.27	
Cylindrocarpon didymum (Harting) Wollenw.	Hypocreales, Sordariomycetes	2.3	7.7							
Cyphellophora oxyspora (W. Gams) Réblová & Unter.[2]	Chaetothyriales, Eurotiomycetes				4.6			13.47	5.27	4.62
Cytospora sp.[4]	Diaporthales, Sordariomycetes							3.47		
Diatrypella quercina (Pers.) Cooke	Xylariales, Sordariomycetes					1.27				
Dicranidion fragile Harkn.	Orbiliales, Orbiliomycetes	6.0					6.9	10.55		
Drechslera biseptata (Sacc. & Roum.) M.J. Richardson & E.M. Fraser	Pleosporales, Dothideomycetes		3.8	30						
Epicoccum nigrum Link					0.9			4.45	0.92	
Exophiala jeanselmei (Langeron) McGinnis & A.A. Padhye[4]	Chaetothyriales, Eurotiomycetes	6.9						1.38		

Taxa	Order, Class	Oak						Scots pine		
		Drawa National Park			Smolarz Forest District			Torzym Forest District		
		Wood decay rate								
		1	2	3	1	2	3	1	2	3
Fusarium sporotrichioides Sherb. + *Gibberella avenacea* R.J. Cook + *G. zeae* (Schwein.) Petch.[4]	Hypocreales, Sordariomycetes	9.7	0.7				4.1		0.66	
Gliomastix murorum (Corda) S. Hughes		2.3	0.7							
Harpophora radicicola (Cain) W. Gams	Magnaporthales, Sordariomycetes					27.8				
Humicola grisea Traaen[1] + *Humicola* sp.	Sordariales, Sordariomycetes	13.4	5.5		4.6					
Hypoxylon fragiforme (Pers.) J. Kickx f.	Sordariales, Sordariomycetes					2.28				
Kretzschmaria deusta (Hoffm.) P.M.D. Martin	Xylariales, Sordariomycetes				0.25					
Lasiadelphia lasiosphaeriae (W. Gams) Réblová & W. Gams	Sordariales, Sordariomycetes	2.3								
Lecanicillium lecanii (Zimm.) Zare & W. Gams[3]	Hypocreales, Sordariomycetes							1.11	0.27	
Lecythophora hoffmannii (J.F.H. Beyma) W. Gams & McGinnis [1,2]+ *Lecythophora* sp.[2]	Coniochaetales, Sordariomycetes	12.0	13.9		25.9			40.27	41.63	12.02
Mariannaea elegans (Corda) Samson[1,2]	Hypocreales, Sordariomycetes	2.3		16.7				4.86	8.69	57.4
Monacrosporium sclerohypha (Drechsler) Xing Z. Liu & K.Q. Zhang	Orbiliales, Orbiliomycetes	0.9								
Monochaetia carissae Munjal & J.N. Kapoor	Xylariales, Sordariomycetes		0.7							
Monodictys putredinis (Wallr.) S. Hughes[1]	Incertae sedis, Dothideomycetes	4.6	3.5		18.5					
Mycelium radicis atrovirens Melin[4]			1.0					0.69		
Myriodontium keratinophilum Samson & Polon.[4]	Incertae sedis, Incertae sedis						20.8		1.38	

Taxa	Order, Class	Oak						Scots pine		
		Drawa National Park			Smolarz Forest District			Torzym Forest District		
		Wood decay rate								
		1	2	3	1	2	3	1	2	3
Myrmecridium schulzeri (Sacc.) Arzanlou, W. Gams & Crous[1,2]	Incertae sedis, Sordariomycetes	2.3		30.0				7.36	2.78	13.9
Nectria cinnabarina (Tode) Fr. [4] + *Nectria* sp.	Hypocreales, Sordariomycetes					0.25		2.08		
Oidiodendron tenuissimum (Peck) S. Hughes[1,2,3]	Leotiomycetes, Incertae sedis	3.3	17.4		9.2			11.7	3.24	
Ophiostoma canum (Münch) Syd. & P. Syd. [3]+ *Ophiostoma* sp.	Ophiostomatales, Sordariomycetes	0.4						8.89		
Paecilomyces variotii Bainier + *Paecilomyces* sp.[4]	Eurotiales, Eurotiomycetes		1.4						1.93	
Paraconiothyrium fuckelii (Sacc.) Verkley & Gruyter	Pleosporales, Dothideomycetes	3.2						0.55	1.38	
Penicillium adametzii Zaleski[1] + *P. aurantiogriseum* Dierckx + *P. canescens* Sopp. + *P. citrinum* Thom[1,2] + *P. commune* Thom[1,2] + *P. daleae* Zaleski + *P. dierckxii* Biourge + *P. glabrum* (Wehmer) Westling[2] + *P. janczewskii* Zaleski [2]+ *P. raistrickii* G. Sm. + *P. simplicissimum* (Oudem.) Thom + *P. spinulosum* Thom[1,2] + *P. steckii* Zaleski[1,2] + *P. thomii* Maire + *P. vinaceum* J.C. Gilman & E.V. Abbott + *T. flavus* (Klöcker) Stolk & Samson + *T. funiculosus* (Thom) Samson, N. Yilmaz, Frisvad & Seifert + *T. islandicus* (Sopp) Samson, N. Yilmaz, Frisvad & Seifert [1,2]+ *T. minioluteus* (Dierckx) Samson, N. Yilmaz, Frisvad & Seifert[1] + *T. ruber* (Stoll) Yilmaz, Houbraken, Frisvad & Samson +*T. variabilis* (Sopp) Samson, N. Yilmaz, Frisvad & Seifert[2]	Eurotiales, Eurotiomycetes	80.1	97.7	91.7	61.2	27.8	72.8	45.82	65.96	90.2
Phialocephala botulispora (Cole & W.B. Kendr.) Grünig & T.N. Sieber [3] + *P. dimorphospora* W.B. Kendr. [2]+ *Phialocephala* sp.[2]	Helotiales, Leotiomycetes				16.7			14.4	6.19	21.22

Taxa	Order, Class	Oak						Scots pine		
		Drawa National Park			Smolarz Forest District			Torzym Forest District		
		Wood decay rate								
		1	2	3	1	2	3	1	2	3
Phialophora bubakii (Laxa) Schol-Schwarz[1] + *P. cinerescens* (Wollenw.) J.F.H. Beyma + *P. clavispora* W. Gams [1,2]+ *P. lagerbergii* (Melin & Nannf.) Conant[3] + *P. verrucosa* Medlar [4]	Chaetothyriales, Eurotiomycetes	23.1	7.3		13.9			21.12	49.74	21.3
Phoma eupyrena Sacc.[4]+ *P. glomerata* (Corda) Wollenw. & Hochapfel [4] + *P. minutella* Sacc. & Penz.+ *Phoma* sp.	Pleosporales, Dothideomycetes	0.4	3.5		4.6			3.74	1.01	
Pleonectria cucurbitula (Tode) Hirooka, Rossman & P. Chaverri	Hypocreales, Sordariomycetes								0.55	
Pochonia bulbillosa (W. Gams & Malla) Zare & W. Gams[1,2]		5.1	15.3	56.6	12.9		84.7	10.56	46.7	23.3
Porosphaerella cordanophora E. Müll. & Samuels[1]	Chaetosphaeriales, Sordariomycetes	12.1	9.7	16.6		100.0	13.9			
Pseudogymnoascus pannorum (Link) Minnis & D.L. Lindner[1]	Incertae sedis, Leotiomycetes,	9.2	15.3	10.0			6.9	2.78	0.67	
Pyrenochaeta cava (Schulzer) Gruyter, Aveskamp & Verkley[4] + *Pyrenochaeta* sp.	Pleosporales, Dothideomycetes	2.7						5.55	0.27	
Ramichloridium apiculatum (J.H. Mill., Giddens & A.A. Foster) de Hoog[4]	Capnodiales , Dothideomycetes	2.3							0.55	
Rhinocladiella atrovirens Nannf. [1,2]	Chaetothyriales, Eurotiomycetes	29.2	13.9		9.2		8.3	28.45	47.1	27.72
Sarocladium strictum (W. Gams) Summerb [2]	Hypocreales, Sordariomycetes	6.0						10.55	12.12	7.4
Sclerotinia sclerotiorum (Lib.) de Bary	Helotiales, Leotiomycetes				0.9					
Septonema secedens Corda	Incertae sedis, Dothideomycetes					55.5				
Septotrullula bacilligera Höhn.[4]	Incertae sedis, Pezizomycotina								1.38	
Simplicillium lamellicola (F.E.V. Sm.) Zare & W. Gams [1]	Hypocreales, Sordariomycetes	4.6		66.6		72.2	13.9	5.56	0.55	

Taxa	Order, Class	Oak						Scots pine		
		Drawa National Park			Smolarz Forest District			Torzym Forest District		
		Wood decay rate								
		1	2	3	1	2	3	1	2	3
Sordaria fimicola (Roberge ex Desm.) Ces. & De Not.[3]	Sordariales, Sordariomycetes							0.55		
Sphaeropsis sapinea (Fr.) Dyko & B. Sutton	Botryosphaeriales, Dothideomycetes							7.3		
Sporothrix schenckii Hektoen & C.F. Perkins[1,2]	Ophiostomatales, Sordariomycetes	31.0	37.8	53.3	27.8		50.0	4.44	4.72	25.9
Sydowia polyspora (Bref. & Tavel) E. Müll.[3]	Dothideales, Dothideomycetes							58.3		
Sympodiella acicola W.B. Kendr.	Incertae sedis, Pezizomycotina		2.7							
Therrya fuckelii (Rehm) Kujala	Rhytismatales, Leotiomycetes							0.5		
Torula sp.[3]	Incertae sedis, Pezizomycotina									9.25
Trichoderma atroviride P. Karst.[1] + *T. aureoviride* Rifai +*T. deliquescens* (Sopp) Jaklitsch [4] + *T. fertile* Bissett + *T. hamatum* (Bonord.) Bainier [1,2] + *T. harzianum* Rifai [1,2]+ *T. koningii* Oudem.[1,2] + *T. polysporum* (Link) Rifai [3]+ *T. pubescens* Bissett +*T. virens* (J.H. Mill., Giddens & A.A. Foster) Arx [3]+ *T. viride* Pers.[1,2]	Hypocreales, Sordariomycetes	82.9	87.5	100.0	50.7	100.0	100.0	56.91	100.0	100.0
Truncatella angustata (Pers.) S. Hughes	Xylariales, Sordariomycetes							6.67	0.55	
Westerdykella minutispora (P.N. Mathur) Gruyter, Aveskamp & Verkley	Pleosporales, Dothideomycetes							3.33		
Xylaria hypoxylon (L.) Grev.	Xylariales, Sordariomycetes		3.2	2.3						

Taxa	Order, Class	Oak						Scots pine		
		Drawa National Park			Smolarz Forest District			Torzym Forest District		
		Wood decay rate								
		1	2	3	1	2	3	1	2	3
Inne Ascomycota spp. – 10 species		7.4	0.7		2.7			10.55	10.22	
Basidiomycota										
Armillaria gallica Marxm. & Romagn.	Agaricales, Agaricomycetes	5.6	15.6		8.1	12.21				
Armillaria ostoyae (Romagn.) Herink								0.8		
Bjerkandera adusta (Willd.) P. Karst.	Polyporales, Agaricomycetes	0.75	2.55						5.09	2.78
Ceratobasidium sp.	Cantharellales, Agaricomycetes							1.24	0.27	
Coniophora puteana (Schumach.) P. Karst.	Boletales, Agaricomycetes			1.1			0.57		9.89	
Crepidotus variabilis (Pers.) P. Kumm.	Agaricales, Agaricomycetes								18.58	4.62
Dacrymycetes	Dacrymycetes			5.05						
Diplomitoporus flavescens (Bres.) Domański	Polyporales, Agaricomycetes								0.5	
Fomes fomentarius (L.) Fr.			0.5	1.52						
Fomitiporia robusta (P. Karst.) Fiasson & Niemelä	Hymenochaetales, Agaricomycetes		1.01							
Ganoderma applanatum (Pers.) Pat.	Polyporales, Agaricomycetes	1.5	7.8	0.7						
Heterobasidion annosum (Fr.) Bref,	Russulales, Agaricomycetes							5.7	9.2	
Hormographiella sp.	Agaricales, Agaricomycetes							4.44		
Hyalodendron sp.[1,2]	Tremellales, Tremellomycetes	0.4	1.4		9.2	63.8		4.45	5.09	2.78

Taxa	Order, Class	Oak						Scots pine		
		Drawa National Park			Smolarz Forest District			Torzym Forest District		
		Wood decay rate								
		1	2	3	1	2	3	1	2	3
Hypholoma fasciculare (Huds.) P. Kumm.	Agaricales, Agaricomycetes								2.1	
Hypholoma lateritium (Schaeff.) P. Kumm.			4.04			0.76				
Hymenochaete rubiginosa (Dicks.) Lév.	Hymenochaetales, Agaricomycetes			6.06			12.18			
Ischnoderma resinosum (Schrad.) P. Karst.	Polyporales, Agaricomycetes		1.01							
Kuehneromyces mutabilis (Schaeff.) Singer & A.H. Sm.	Agaricales, Agaricomycetes		2.02							
Lycoperdon pyriforme Schaeff.	Agaricales, Agaricomycetes						0.25			
Meripilus giganteus (Pers.) P. Karst.	Polyporales, Agaricomycetes		1.01							
Merulius tremellosus Schrad.			1.01							
Panellus serotinus (Pers.) Kühner	Agaricales, Agaricomycetes		3.03							
Peniophora pini (Schleich.) Boidin	Russulales, Agaricomycetes							1.6		
Peniophora quercina (Pers.) Cooke						0.25				
Phanerochaete velutina (DC.) P. Karst.	Polyporales, Agaricomycetes									3.6
Phlebia radiata Fr.			3.2	1.3						
Phlebia rufa (Pers.) M.P. Christ.						2.03				
Phlebiopsis gigantea (Fr.) Jülich[4]		5.1						0.69	0.27	
Porodaedalea pini (Brot.) Murrill	Hymenochaetales, Agaricomycetes								1.6	
Postia subcaesia (A. David) Jülich	Polyporales, Agaricomycetes	3.5	4.2							
Ramaria pallida (Schaeff.) Ricken	Gomphales, Agaricomycetes								0.3	

Taxa	Order, Class	Oak						Scots pine		
		Drawa National Park			Smolarz Forest District			Torzym Forest District		
		Wood decay rate								
		1	2	3	1	2	3	1	2	3
Resinicium bicolor (Alb. & Schwein.) Parmasto	Incertae sedis, Agaricomycetes									2.5
Steccherinum ochraceum (Pers.) Gray	Polyporales, Agaricomycetes								0.8	
Stereum hirsutum (Willd.) Pers.	Russulales, Agaricomycetes	1.1	2.1						0.8	
Stereum rugosum Pers.						0.76				
Tritirachium oryzae (Vincens) de Hoog	Tritirachiales, Tritirachiomycetes	2.8	0.7				6.9	1.38	9.89	
Trametes hirsuta (Wulfen) Lloyd	Polyporales, Agaricomycetes	1.9	2.5							
Trametes ochracea (Pers.) Gilb. & Ryvarden						0.25				
Trichaptum fuscoviolaceum (Ehrenb.) Ryvarden	Hymenochaetales, Agaricomycetes						1.8	2.9		
Typhula sp.	Agaricales, Agaricomycetes								1.0	1.6
Xanthoporia radiata (Sowerby) Ţura, Zmitr., Wasser, Raats & Nevo	Hymenochaetales, Agaricomycetes		1.45	0.75						
Inne Basidiomycota spp. – 8 species		1.0					18.0	17.23	18.58	4.62

Explanations

[1] – species common on the oak wood

[2] – species common on the Scots pine wood

[3] – in pine, in managed area only

[4] – in pine, in unmanaged area only

stage of decomposition. *Armillaria Galica, A. ostoyae* and *Heterobasidion annosum* occurred on wood of oak and pine respectively only in the initial stages of rot (Table 1).

Crawford et al. (1990), Lumley et al. (2001), Fukasawa et al. (2009, 2010) and Kim et al. (2009) observed that Basidiomycota dominated in the initial stages of wood decomposition, which was later replaced by Ascomycota. Our observations indicate that Basidiomycota occur much less frequently than Ascomycota in each stage of decomposition. In oak wood, there were more Basidiomycota fungi in the initial stages of wood decomposition, in comparison to pine wood.

Wood humidity is often a determinant of colonization and its effects. Particularly, strong influence of high humidity (= 200%) on decomposition of wood by *T. harzianum* was observed by Fukasawa et al. (2011). On pine wood examined by us, *T. harzianum,* observed belonged to the dominant species in 1 and 2 stage of decomposition. That seems to be confirming the suggestions regarding strong humidity preferences of this fungus. The latter relate to specifics of lignin and cellulose hydrolysis.

Range of species in fungi succession on wood of oak and pine was similar only in 37% cases. The stated was nutritional or ecological specialization of other species. Those latter also occurred occasionally or locally. However, they should not be ignored. Rare fungi often have specific enzymatic abilities that allow them to complement food deficiencies of plants and other organisms in the ecosystem. Rare or local species are extremely vulnerable to extinction.

Global warming, lowering of the level of ground water and drying of large areas of Poland (Kamińska 2013) does not influence favourably on preserving the biological diversity of fungi. With reference to the above, dead wood should be treated as an essential element in the improvement of situation and maintaining ecological balance.

Conclusion

The decrease in number of fungi that help in progressing decomposition indicates the necessity to systematically leave fresh parts of dead wood. It provides continuity of development process of fauna and flora, and guarantees stable development of forest stands. It seems appropriate to supplement dry-wood with wood of different species of trees when taking into consideration nutritional and ecological specialization of many species of fungi.

Conflict of interest

The authors declare lack of potential conflicts.

Acknowledgements and sources of funding

The research was financed from the resources of General Directorate of State Forests in Warsaw 'Forest stands utilization versus threshold value of dead wood in forest – a role in preserving functionality and biodiversity of forest ecosystem', in years 2012–2015.

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Authors' contribution

H.K – implementation mycological analyses, writing an article; A.M. – collection of research materials, literature review; A.Ł. – collection of research materials, literature review; R. K. – collection of research materials, literature review; P.L. – concept of research, establishment of experience.

Translated by: Anna Wyszyńska