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Evaluation of forest ecosystems' anthropogenic transformation by indicators of xylomycocomplex

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Abstract

The aim of our work was to establish the dependence of species composition, features of ecosystem distribution in the space and wood-destroying activity of xylotrophs on the functional type of forest, and the cause and degree of its violation. Changes in species composition, spatial distribution and wood-destroying activity of xylotrophic fungi, and disruption of "woody plant xylomycobiont", "substrate category – xylomycobiont," were revealed. Changes in xylotrophic diversity in stands were evaluated by diversity indices. Forest and taxonomic characteristics of stands, the reasons and the degree of degradation of forest ecosystems were taken into account. The ability of 37 species of xylotrophs to be indicators of deciduous and coniferous forests in green areas of cities due to recreation, construction and quarrying of granite has been substantiated. The principles of application of the mycoindicators system for improvement, a technique of estimation of character and degree of forest ecosystem anthropogenic transformation, are defined.

Key words

ecological community, forest, biodiagnostics, xylotrophic fungi, indicative ability

Introduction

Forests or green areas around cities and other settlements perform environmental, recreational, health, protective and other valuable functions for humans and many communities and related ecosystems. However, non-compliance with environmental standards in the economy, urban planning and nature management in general and the excessive impact of various negative factors, such as plowing of lands and town planning, lead to the disruption and fragmentation of the vegetation in these green areas and changes in the structure of their landscapes (Kucheriaviy 2001; Williams et al. 2015; Lavrov et al. 2017; Maltseva et al. 2017; Rat et al. 2017). These damages result in the elimination of unstable species and invasion of non-forest species,

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break ecosystem relationships, change the forest environment, structure, productivity and sustainability, and also lead to ecological role decrease (Wang et al. 2009; Potter and Woodall 2012; Prevosto et al. 2011; Huse et al. 2016; Livesley et al. 2016; Simmons et al. 2016; Abiev et al. 2017).

Forest plantations are often degraded near cities, industrial enterprises and transport communication systems. Diagnostic of anthropogenic disturbance of forest ecosystems is currently detailed at all levels of living organization (Korshikov 1996; Monitoring and Adjustment… 2011). However, assessment and comparative analysis of causation are complicated. They are results of complex interactions of different factors (chemical, physical and biological pollution, mechanical destruction of forest ecosystems on the fluctuation background of natural factors). The search of new methods to improve the diagnosis of forest ecosystem violations is quite relevant. Among the least studied issues is the evolutionary format in forest relationships between woody plants and xylotrophic fungi. They regulate the cycle of substances and chemical elements as well as the dynamics of the structural and functional organization of phytocenoses (Isikov and Konoplya 2005; Medvedev 2006; Arefiev 2010; Blinkova and Ivanenko 2014, 2016, 2018; Lavrov et al. 2017).

The wood-destroying fungi are usually characterised by macro-taxonomic indicators of the organic world organization, anatomical, morphological and functional parameters of the structure (Storozhenko 2007) and evolutionary characteristics (Bondartseva 2004; Storozhenko 2007). So far, there are not enough data on the features of changes in the xylomycocomplex species structure, its distribution and activation under the complex impact of negative factors (different origins, regimes and action intensities on different components of the ecosystem). The vulnerability and transformation of the xylomycocomplex based on the functional category of the forest, the silvicultural and taxonomic characteristics of stands and their type and structure have been insufficiently studied. We found that these differences exist (Blinkova and Ivanenko 2014, 2016, 2018; Lavrov et al. 2017). It should be expected that the violation of the taxonomic structure of stands (species composition, canopy density, mortality structure, etc.) will lead to changes in forest environment conditions, quantitative and qualitative characteristics of substrates and habitats; and change in the species structure of fungi xylotrophs, the levels of damaged trees, the rate of their subsequent mortality (or recovery) and degradation or restoration of the forest ecosystem. Therefore, this study aimed to identify and characterise changes in the species composition of wood-destroying fungi, their destructive activity and distribution of the forest ecosystem depending on the type of forest, tree species and rate of anthropogenic impact, finding out their indicator capabilities.

Material and methods

The research was carried out on the example of sub-oak and oak forest types of protective, recreational health and nature protection forests of the green zones of the Ukrainian cities (Tab. 1). In Kyiv Polissya, forests in fresh sub-forests (type of forest according to

Table 1. Taxonomic structure of aphylophoroid fungi found in the studied forests of green areas of Kyiv ("Lyman Oshytky" tract, Lake Ebisu), Bila Tserkva ("Tovsta" tract, "Koshyk" tract) and Uman ("Bilogrudivska Dacha" tract)

Orders	Families	Species	Tracts in which fungi were found
1	2	3	4
Agaricales	Physalacriaceae	*Cylindrobasidium evolvens* (Fr.) Jülich	"Koshyk" tract
	Pterulaceae	*Radulomyces molaris* (Chaillet ex Fr.) Christ.	"Lyman Oshytky" tract; "Koshyk" tract; "Bilogrudivska Dacha" tract
	Schizophyllaceae	*Schizophyllum commune* Fr.*	"Lyman Oshytky" tract; "Koshyk" tract; "Bilogrudivska Dacha" tract
Auriculariales	Exidiaceae	*Exidia glandulosa* (Bull.) Fr.	"Bilogrudivska Dacha" tract
		E. truncata Fr.	"Bilogrudivska Dacha" tract
	Auriculariaceae	*Auricularia mesenterica* (Dicks.) Pers.	"Tovsta" tract
Boletales	Paxillaceae	*Paxillus involutus* (Batsch) Fr.*	"Lyman Oshytky" tract

1	2	3	4
Corticiales	Corticiaceae	*Dendrothele acerina* (Pers.) P.A. Lemke	"Koshyk" tract; "Tovsta" tract
		Dendrothele alliacea (Quél.) P.A. Lemke	"Tovsta" tract
		Vuilleminia comedens (Nees) Maire	"Lyman Oshytky" tract; "Koshyk" tract; "Bilogrudivska Dacha" tract
Hymenochaetales	Hymenochaetaceae	*Hymenochaete rubiginosa* (Dicks.) Lév.	"Koshyk" tract; "Tovsta" tract; "Bilogrudivska Dacha" tract
		Phellinus ferruginosus (Schad.) Pat.	"Koshyk" tract; "Bilogrudivska Dacha" tract
		Phellinus robustus (P.Karst.) Bourdot et Galzin*	"Lyman Oshytky" tract; "Koshyk" tract; "Tovsta" tract; "Bilogrudivska Dacha" tract
		Phellinus punctatus (P.Karst.) Pilát	"Koshyk" tract
		Phellinus contiguus (Pers.) Pat.	"Tovsta" tract
		Phellinus igniarius (L.) Quél.*	"Tovsta" tract
		Phellinus laevigatus (Fr.) Bourdot et Galzin	"Tovsta" tract
	Schizoporaceae	*Oxyporus corticola* (Fr.) Ryvarden	"Koshyk" tract; "Tovsta" tract
		Schizopora flavipora (Berk. et M.A. Curtis ex Cooke) Ryvarden	"Koshyk" tract; "Tovsta" tract
		Schizopora paradoxa (Schrad.) Donk	"Koshyk" tract
Polyporales	Fomitopsidaceae	*Laetiporus sulphureus* (Bull.) Murrill*	"Lyman Oshytky" tract; "Koshyk" tract; "Tovsta" tract
		Fomitopsis pinicola (Sw.) P. Karst.*	"Lyman Oshytky" tract
	Meruliaceae	*Hyphoderma setigerum* (Fr.) Donk	"Koshyk" tract
		Phlebia radiata Fr.	"Tovsta" tract
	Phanerochaetaceae	*Hapalopilus rutilans* (Pers.) Murrill, 1904	"Bilogrudivska Dacha" tract
		Steccherinum fimbriatum (Pers.) J. Erikss.	"Bilogrudivska Dacha" tract
		Phanerochaete laevis (Fr.) J. Erikss. et Ryvarden	"Koshyk" tract
		*Irpex lacteu*s (Fr.) Fr.*	"Tovsta" tract
	Polyporaceae	*Daedaleopsis confragosa* var. *tricolor* (Bull.) Bondartsev et Singer	"Bilogrudivska Dacha" tract
		Lenzites betulina (L.) Fr.*	"Bilogrudivska Dacha" tract
		Trichaptum biforme (Fr.) Ryvarden*	"Bilogrudivska Dacha" tract
		Trametes versicolor (L.) Lloyd*	"Koshyk" tract
		Trametes hirsuta (Wulfen) Pilát*	"Tovsta" tract
		Trametes pubescens (Schumach.) Pilát*	"Lyman Oshytky" tract; "Tovsta" tract
		Fomes fomentarius (L.) Fr.*	"Lyman Oshytky" tract; "Tovsta" tract
		Piptoporus alveolaris (DC.) Bondartsev et Singer	"Tovsta" tract
		Piptoporusbetulinus (Bull.) P. Karst*	"Bilogrudivska Dacha" tract; "Tovsta" tract
		Piptoporus squamosus (Huds.) Fr.	"Tovsta" tract
Russulales	Peniophoraceae	*Peniophora laeta* (Fr.) Donk	"Bilogrudivska Dacha" tract
		Peniophoracinerea (Pers.) Cooke	"Koshyk" tract
		Peniophora quercina (Pers.) Cooke	"Bilogrudivska Dacha" tract; "Koshyk" tract
	Stereaceae	*Stereum gausapatum* (Fr.) Fr.	"Koshyk" tract
		Stereum hirsutum (Willd.) Pers.*	"Koshyk" tract; "Lyman Oshytky" tract
		Stereum subtomentosum Pouzar*	"Koshyk" tract; "Lyman Oshytky" tract
Thelephorales	Thelephoraceae	*Thelephora terrestris* Ehrh., Pl. Crypt. Linn. Exsicc*	"Lyman Oshytky" tract
Tremellales	Tremellaceae	*Tremella mesenterica* (Schaeff.) Retz.	"Bilogrudivska Dacha" tract
Total: 9	17	46	–

Notes: species are indicators of different types and degrees of anthropogenic impact on forests with different species compositions.

the (Pogrebnyak 1955; Migunova 2014) C_2–hoS (fresh hornbeam oak sub-oakery); *Quercus robur* L. aged 100–120 years), recreationally transformed to stages II–III of digression, were studied around Lake Ebisu in the "Lyman Oshytky" tract near the Dnieper (green zone of Kyiv). In the Right-Bank of Forest-Steppe, the recreational impact on fresh maple oakery (D_2–moO) forests in the "Bilogrudivska Dacha" tract (green zone of Uman; 45–90 years old *Q. robur* stands) was studied, as well as the impact of a complex anthropogenic factors on the green zone of Bila Tserkva (D_2–hO – fresh hornbeam oakery): "Golenderna" tract of the "Olexandria" Arboretum of the National Academy of Sciences of Ukraine (*Q. robur* 213 years), protective and recreational health forests of "Tovsta" tracts (*Q. robur* 70–110 years) and "Koshyk" (*Q. robur* 80–170 years). Natural and climatic conditions of the study areas are favourable for the development of forest vegetation and xylomycocomplex. However, in the south of Kyiv region, there was a lack of precipitation during the growing season (by 52%–68%), and the air temperature increased by 84.6%–141.6%. Nevertheless, these did not affect the subjects of study – the structure of phytocoenosis and mycocoenosis. A study was conducted in 2016–2018. The study was conducted using standard methods of forestry, forest science and forest mensuration (Vorobyov 1967; Anuchin 1982). The health condition of trees (category of tree state) was appraised following the Sanitary Forest Regulation in Ukraine (2016). Field research was conducted by mycoindication's method of violations of forest ecosystems (Arefiev 2010; Blinkova and Ivanenko 2018). Based on comparative ecology and forest taxation, an ecological profile of several sample plots (SP) and their sections (S1 – intensive, S2 – medium, S3 – moderate impact) was laid in representative forest areas from the source of threat. Their location was determined by Google Earth maps and global positioning system (GPS). At each section (S1–S3) of the SP of ecological profiles by indicators of direct and indirect impact, the following was revealed: (1) structural (quantitative and qualitative) changes along the eco-profile in the main components of the ecosystem: stand undergrowth shrub layer, herbaceous layer, forest litter and soil surface; (2) according to these data, we found out how the conditions of the forest environment have changed, analysing the transformation in the species composition of xylotrophs, active visible fungal growth and distribution in the forest (by the share of trees where fruiting bodies of fungi found) and mycohorizons in the ecosystem (Blinkova and Ivanenko 2018); (3) we compared the studied indicators with the gradients of influencing factors. Species of aphilophoroid fungi were identified in the forest by the methods of A. Bernicchia (2006), A. Bernicchia et al. (2010), H. Clemenzon (2009) and in the laboratory of the Institute of Evolutionary Ecology of the National Academy of Sciences of Ukraine; the nomenclature of species is based on online databases (mycobank.org). The population of fungi of dead substrates was assessed separately: dead trees, fallen trunks, large and small branches and tree stumps. Carpophores of one species of fungus on several substrates of one tree were considered one specimen. Instead, one substrate coated with carpophores of several species of aphilophoroid fungi was considered a different finding. There were first-order eurythrophs (EI, consorts of both deciduous and coniferous trees), second-order eurythrophs on deciduous (EIId) and stenotrophs (S, consorts mainly of one genus of woody plants). The analysis of the consortial formed link "tree-xylotroph" was evaluated by Blinkova and Ivanenko (2014, 2016, 2018). Decay stages of wood and associated fungal communities were assessed by Fukasawa and Matsukura (2021). The composition of forest stands was characterised by the ratio of trunk wood stock of each tree species that makes up the first layer of the stand. This composition is written in the form of a formula in which the tree species is indicated in capital letters and numbers reflect the participation of the tree species in the total stock of the stand. The sum of all numerical coefficients should be equal to 10. If in this stand the breed is from 2% to 5%, then "+" is used; if 2%, then "s" (single) is used (example: $7Q_r2T_c1A_p$+P_as.R_p) (Anuchin 1982).

The recreational impact on forest ecosystems was assessed by accepted methods. The stage of recreational soil digression was assessed by the Poliakov and Plugatar (2009) method. Stages of recreational digression of the forest ecosystem environment were assessed by Voron et al. (2008) of forest management in Ukraine: stage I – grass and moss cover unchanged and corresponds to the type of forest, forest litter is not disturbed, undergrowth and understorey correspond to forest vegetation conditions and are not damaged; stage II – grass and moss cover is slightly damaged, this tier is preserved, undergrowth and understorey in satisfactory and good condition (75%–90% of trees are in good and satisfactory condition); stage III – grass and moss cover is damaged over a large area, the number of forest and forest meadow grasses decreased, there are weeds or meadow grasses that are not typical for forest vegetation conditions, the layer of the cover is still preserved, the surviving undergrowth is poorly differentiated, and there are almost no seedlings of native forest-forming species; stage IV – the grass and moss cover degrades, the phytomass and the number of weeds and meadow plants have sharply increased, litter is significantly damaged, the structure of the phytocenosis is in the form of alternation of understorey curtains and low-viable undergrowth, limited by meadows and paths; stage V – grass and moss cover, typical for forest vegetation conditions of the site, degraded, the cover and phytomass of weeds and meadow plants are much larger than those of forest plants that have survived only near tree trunks, litter is almost complete demolition, undergrowth and understorey are almost completely absent, the illumination under the tent of the stand has sharply increased, and trees have mechanical damage, dried up. In most trees, the roots are bare and protrude (Lavrov et al. 2018). Mathematical processing of the research results was carried out according to the evaluation indicators of the richness of biodiversity in communities following the recommendations (Magurran 2004). The diversity of xylotrophic fungi communities was analysed according to the Shannon diversity index, Berger–Parker dominance index and McIntosh evenness index. Mathematical and statistical data processing was performed using the software “Statistica 6.0”.

Results

Forests or green areas of Kyiv, Bila Tserkva and Uman have signs of recreational digression: littering of the territory, a network of trails, trampling of forest litter, topsoil and living ground cover, mechanical and pyrological damage to trees and their development, suppression, natural regeneration, deterioration of stands and decrease of stocking density of forest. These negative consequences increase with the decreasing distance to the sources of threats – settlements, recreation areas and transport communications. Recreational changes have certain features depending on the silvicultural and taxonomic characteristics of stands of certain functional categories, as well as the type and degree of anthropogenic load (Tab. 2 and 3). Thus, in the forests of Kyiv Polissya within a radius of 400 m from Lake Ebisu in the most degraded (stage III of recreational transformation) and weakened stands (Is=1.70–2.71) of 14 xylotroph species, *Lycoperdon pyriforme* Schaeff. is the most common on *Q. robur*. The early and late stages of wood decomposition are caused by: *Crepidotus variabilis* (Pers.) *Pleurotus* Kumm., *Gloeoporus dichrous* (Fr.) Bres., *Lenzites betulina* (L.) Fr., *L. pyriforme*, *Phellinus robustus* (P. Karst.) Bourdot and Galzin, *Fistulina hepatica* (Schaeff.) ex Fr. The number of xylotrophic species (from 17 to 9) and their finds (from 53 to 25) is reduced twice and the damage to the stands increases as we approach Lake Ebisu. Conversely, the proportion of biotrophic species that develop most actively on weakened and severely weakened individuals of *Q. robur* doubles (Tab. 2). The distribution of xylotrophs on mycohorizons of forest ecosystem does not change along the eco-profile. The average threats to *Q. robur* trees are *Laetiporus sulphureus* (Bull.) Murril and *Ph. robustus*; their share is 8.5% among xylomycobionts parasites. *Ph. robustus* is a eurythroph of the second order; at the first stage of development – a saprophyte, then – a parasite, provokes the development of white rot in *Q. robur*.

Xylotrophs were found on *Pinus sylvestris* L. and *Betula pendula* Roth, trees less damaged than *Q. robur* (respectively, three and two times less than on *Q. robur*). However, *B. pendula* trees are more damaged by polypores. Most species and findings of xylotrophs were found on medium and large branches on the soil surface among the dead waste substrate. Changes in the diversity of xylotrophs were best illustrated by the Berger–Parker dominance index (Tab. 4). Compared with the green zone of Kyiv, around Uman (“Bilogrudivska Dacha” tract), the recreational load on forests is much less – I (75%) and II (25%). This forest is under recreational digression (stage I – 75% of the territory; II – 25%). The main forest-forming species (oak, hornbeam, ash, birch) are drying up. The stock of dead trees at the sample plots of the forest is from 5 to 10 m^3/ha. The intensive and medium impact of visitors is local in attractive and

Table 2. Distribution of species and finds of xylotrophic fungi in stands of different health conditions on the eco-profile with distance from Lake Ebisu (Kyiv Polissya)

№ SP	Distance from the lake, m	Species composition of the stand	Tree species	Age, yrs	Health condition index		Distribution of xylotrophs in forest ecosystems, units		The share of xylotrophs from their number at the eco-profile, %
					tree species	stand	species	finds	
1	100	$5Q_r3P_s2B_p$	*Quercus robur* L.	100	2.71	2.55	4	13	21
			Pinus sylvestris L.	80	1.75		2	4	5
			Betula pendula Roth.	80	1.65		3	8	17
Total in the stand					2.55		9	25	43
2	400	$7Q_r2P_s1B_p$	*Quercus robur* L.	105	1.95	1.75	6	15	25
			Pinus sylvestris L.	60	1.70		2	5	5
			Betula pendula Roth.	60	1.90		8	9	22
Total in the stand					1.75		16	29	52
3C	800	$7Q_r2P_s1B_p$	*Quercus robur* L.	120	1.70	1.60	8	28	15
			Pinus sylvestris L.	100	1.65		2	9	5
			Betula pendula Roth.	80	1.50		7	16	7
Total in the stand					1.60		17	53	27

Notes: SP – sample plot, C – control.

accessible suburban places with unorganised recreation and sports, as well as in the suburban (up to 30 m) forest belts adjacent to communication routes. It has been found that the proportion of mechanical damages to tree trunks, their area and prevalence are higher near sports grounds, picnic lawns, roads and tracts. Six percent to 16% of trees have mechanical damage in the trunk area up to height of 0.3–2.1 m (Tab. 3).

Table 3. Characteristics of mechanical damage to tree trunks in the tract "Belogrudivska Dacha" in the green zone of Uman

№ SP-S; W, m²; N, pieces	Taxation of the first tier of the stand	Damaged trees		The area of wounds on tree trunks, S, m²	The height of the wounds on the trunks, h, m
		N_d, pieces	Q, %	M ± m / $S_{TP} – S_{1ha}$	M ± m / min –max
Forest areas of intensive and medium load around the sports ground					
SP1-1, W = 450, N = 84	$7Q_r2T_c1A_p + P_as.R_p$; CD – 0.87	13	15.5	0.328 ± 0.147 / 4.13 – 91.77	1.14 ± 0.15 / 0.3 – 2.1
SP1-2, W = 450, N = 67	$7Q_r2T_c1A_p$; CD – 0.87	9	13.4	0.242 ± 0.062 / 2.18 – 48.44	1.00 ± 0.12 / 0.3 – 1.7
Areas of forest of medium and moderate load on picnic meadows					
SP2-2, W = 900, N = 71	$10Q_r$; CD – 0.81	7	9.9	0.186 ± 0.034 / 1.30 – 14.44	1.24 ± 0.10 / 0.9 – 1.8
SP2-3, W = 900, N = 69	$10Q_r$; CD – 0.81	4	5.8	0.173 ± 0.035 / 0.69 – 7.67	1.33 ± 0.04 / 1.1 – 1.5

Notes: SP – sample plot; S – sections in the SP, depending on the impact of recreation: intensive – S1, medium – S2, moderate – S3 (control); characteristics of the stand: W – area of the section of the test area (m²), N – the number of surveyed trees per S, CD – canopy density; characteristics of mechanical wounds on trees of sections of SP: Nd – number of damaged trees, Q – the share of damaged individuals from all trees (%), S_{TP} – total area of SP (m²/ha), S_{1ha} – total area per 1 ha (m²/ha); height of wounds on tree trunks h (m): M ± m – average, max – maximum, min – minimum, in section S3, mechanical wounds were found on only 1% of trees; Q_r – *Quercus robur* L.; T_c – *Tilia cordata* Mill.; A_p – *Acer platanoides* L.; P_a – *Prunus avium* (L.) L.; R_p – *Robinia pseudoacacia* L.

Table 4. Changes in the diversity of xylotrophs in the *Quercus robur* L. stands of the "Lyman Oshytky" tract in Kyiv Polissya depending on the distance to Lake Ebisu

№ SP	Distance, m	Shannon's diversity index	Berger–Parker dominance index	McIntosh evenness index
1	100	1.80 ± 0.09	0.44 ± 0.02	0.71 ± 0.04
2	400	2.83 ± 0.4	0.51 ± 0.02	0.75 ± 0.04
3C	800	2.89 ± 0.14	0.68 ± 0.03	0.69 ± 0.03

Notes: SP – sample plot, C–control.

The generalised analysis of the state stand in all areas of the massive forest of the "Bilogrudivska Dacha" tract showed that depending on the degree of recreational forest digression, the average (r = 0.97) and total area (r = 0.98) of mechanical trunk wounds increased, as well as the share of damaged trees. It is in these areas that the trampling of forest litter and the topsoil was the greatest, which depended on the distance to the sources of environmental threats (edges, roads, places of recreation or sports). There was a negative correlation between the height of the wounds (r = -0.75) and the area of traces of fires (r = -0.64) and the distance to the sports ground in the forests. The share of damaged trees, as well as the average (r = 0.97) and total (r = 0.98) area of trunk wounds, increased depending on the degree of recreational forest digression. On attractive sports grounds, picnic lawns and edges, the most vulnerable living ground cover was more trampled than forest litter.

In this tract, the distribution and taxonomic structure of wood-destroying fungi change depending on forest and taxonomic characteristics of stands and the distribution of anthropogenic disturbances. Most fungi are found on *Q. robur* trees of Kraft classes I–III. The distribution of xylotrophs depends more on the health condition of the trees: most species (35.7%) and findings of fungi (40.0%) were found in weakened and severely weakened individuals (37.1% and 32.0%). Only a few (7.6%) xylotrophs were found on recently dried *Q. robur*; while on healthy and withering trees, they almost did not occur (up to 4.3%). The distribution of xylotrophs increases with increasing degradation of the stand: weak deterioration represented 23.7% of the findings, medium – 38.4% and strong – 75.0%. The greatest sensitivity to changes in the species diversity of xylotrophs was demonstrated by the Shannon index (Tab. 5). Compared with recreational degression, the impact of several anthropogenic factors on forests leads to a wider range of negative consequences, which complicates their assessment. Thus, in the green zone of Bila Tserkva, in the tract "Tovsta", which is under the complex influence of the city, the share of withering and withered trees of the main species varies in a wide range – from 9% to 70% depending on the forest site conditions and the type of anthropogenic factor. The pre-ripening stand of *B. pendula*, where birch sap was intensively collected, has the worst health condition.

Table 5. Changes in the diversity of xylotrophs in *Quercus robur* L. stands ($7Q_r2T_c1A_p+P_as.R_p$)* of the "Bilogrudivska Dacha" tract depending on the deterioration of forest conditions around the sports ground

№ SP/S	State index of stand	Shannon's diversity index	Berger–Parker dominance index	McIntosh evenness index
1/1	2.63	1.34 ± 0.06	0.40 ± 0.02	0.54 ± 0.02
1/2	2.32	1.60 ± 0.08	0.28 ± 0.01	0.48 ± 0.02
1/3	2.28	2.60 ± 0.13	0.36 ± 0.02	0.69 ± 0.03

* *Quercus robur* L., *Tilia cordata* Mill., *Acer platanoides* L., *Prunus avium* (L.) L., *Robinia pseudacacia* L.
Notes: SP – sample plot; S – sections in the SP.

In total, 20 species (54 finds) of xylotrophic fungi from 14 genera, 8 families, 4 orders of the Agaricomycetes class of the Basidiomycota division on 10 species of deciduous trees were found in the "Tovsta" tract. Let's analyse the structure of the xylomycocomplex on the example of the two closest to the settlements, the most transformed stands *Q. robur*: (1) SP3 (first layer – $9Q_r1A_p$, second layer – $10M_n$, relative stocking density – 0.89, canopy density – 0.93, understorey – $6U_l2A_n2A_p$, undergrowth – 10 P_a) is located on the edge of the forest towards Bila Tserkva, construction without permission in forests in the strip up to 20 m; (2) SP5 plot (first layer – $8Q_r2T_c$, second layer – $10V_l$, stand relative stocking density – 0.87, canopy density – 0.83, understorey – $9V_l1A_p$, undergrowth – $7S_n2P_p1C_a$) on the edge of the forest with unauthorised garbage landfill from the side of Volodymyrivka village. Ten species (30 finds) of xylotrophs of Agaricomycetes class of Basidiomycota division on three species of trees – *Q. robur*, *A. platanoides*, *Ulmus laevis* Pall. – were found in SP3 plantation. The development of seven species (18 finds) of xylotrophs from seven genera, two families, two orders of the Agaricomycetes class of the Basidiomycota division on *Q. robur*, *A. platanoides*, *Tilia cordata* Mill. was recorded in the SP5 stand. Xylotrophs dominated in the stem mycohorizon; they were absent in the soil mycohorizon (Tab. 6). Only on SP3 of "Tovsta" tract the development of *Trametes pubescens* (Schumach.) Pilat and *Vuilleminia comedens* (Nees) Maire was recorded in the above-ground mycohorizon (on dry branches) in places almost untouched by recreation and construction. Xylotrophs are most common on the trunks of dominant and co-dominant *Q. robur* and *U. laevis* (17.9% of findings of *Polyporus squamosus* (Huds.) Fr., *Hymenochaete rubiginosa* (Dicks.) Lev. developed only on the stumps of *Q. robur* (13.1% finds). Dry substrate contains the least fungi (1.8%). Spontaneous landfills in the forest are a greater threat of biological pollution than unauthorised construction of the edge of the forest and recreation from the city.

In the suburban stand SP3, 37.5% of xylotrophic finds on *Q. robur* were distributed on trees of health condition categories I–II, 44.5% on category III, 18% on individuals of health condition category IV. On *A. platanoides*, all species developed on living trees, of which 75.5% are category II of trees. On *U. laevis*, the share of finds on category I of trees was 35.3%, II – 36.8% and III – 10.0%. Xylomycobiota was absent in category IV of trees. On the other hand, 17.9% of *U. laevis* trees were found in category V of trees. According to Kraft classes, the findings predominated in individuals of higher classes – *Q. robur*, *A. platanoides* and *U. laevis*.

In the plantation SP5, where there is a landfill, on one find of *Oxyporus populinus* (Schumach.) Donk (state category I, Kraft class II), *Polyporus. alveolaris* (DC.) Bondartsev and Singer (state category II, Kraft class II) were found on *Q. robur* (state category II–III, Kraft class I–II). *Dendrothele acerina* (Pers.) P.A. Lemke and *D. alliacea* developed on *A. platanoides* trees (condition category II, Kraft class II).

Analysis of the trophic structure of xylotrophs showed that saprotrophs dominated – 66% and 50.1% on TP3 and TP5, respectively (Fig. 1). The share of optional saprotrophs is approximately the same. The contribution of parasites is significant (27.7%) only on TP5, which indicates a greater transformation in this area of ecological conditions of the forest environment. Among the optional parasites, *Ph. robustus* occurs in TP3 and TP5. *Fomes fomentarius* (L.) Fr. developed only on TP5. Both species are indicators of transformed forests. TP3 and TP5 are dominated by eurythrophs of the first (65.0% and 60.0%) and second (35.0% and 40.0%) orders, respectively; no stenotrophs were detected.

Xylotrophs are mainly common in weakened *Q. robur*, *A. platanoides* and *U. laevis*. However, *T. pubescens* and *V. comedens* also occurred in plantations that were almost intact by recreation and construction. In a plantation with a landfill, there are more biotrophs *F. fomentarius* and *Ph. Robustus* – indicators of trans-

Table 6. Distribution of xylotrophs by micro-horizons in the stands of the tract "Tovsta" of the green zone of Bila Tserkva

Fungi species/tree family	Mycohorizon	Substrate, diameter (d), cm	№ SP
Dendrothele acerina (Pers.) P.A. Lemke/*Acer* L.	stem	trunks of living trees, d = 44 – 50	3, 5
D. alliacea (Quél.) P.A. Lemke/*Ulmus* L., *Acer* L.	stem	trunks of living trees, d = 13 – 44	3, 5
Fomes fomentarius (L.) Fr./*Quercus* L.	stem	trunks d = 31 – 36	5
Hymenochaete rubiginosa (Dicks.) Lév./*Quercus* L.	butt	stumps d = 9 – 20	3
Oxyporus populinus (Schumach.) Donk/*Acer* L., *Tilia* L.	butt	trunks d = 40 – 49	3, 5
Polyporus alveolaris (DC.) Bondartsev et Singer/*Acer* L., *Quercus* L., *Ulmus* L., *Tilia* L.	above ground, crown	trunks of living trees, d = 10 – 56, dry branches, d = 5 – 6	3, 5
Phellinus robustus (P.Karst.) Bourdot et Galzin/*Quercus* L.	stem	trunks d = 38 – 69	3, 5
Schizopora paradoxa (Schrad.) Donk/*Quercus* L.	stem, crown	trunks and branches 1st order, d = 10 – 14	3, 5
Trametes pubescens (Schumach.) Pilát/*Ulmus* L.	above ground	dry branches d = 3	3
Vuilleminia comedens (Nees) Maire/*Acer* L., *Quercus* L.	above ground, crown	trunks and branches, d = 25 – 40, dry branches, d = 1 – 2	3

Note: SP – sample plot.

formed forests. However, significantly fewer xylotrophs were on weakened trees – one find of *O. populinus* on *Q. robur*; *P. alveolaris* on *T. cordata*; *D. acerina* and *D. alliacea* on *A. platanoides* trees. Xylo-diversity here is characterised by indicators: H = 1.67±0.08; d = 0.63±0.04; U = 0.75±0.04. In the suburban built-up edge of the forest, they are as follows: H = 1.85±0.09; d = 0.51±0.03; U = 0.87±0.04.

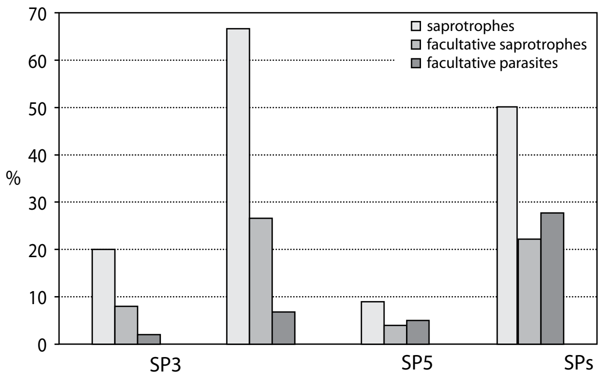

Figure 1. The ratio of trophic groups of xylotrophs in the tract "Tovsta" of the green zone of Bila Tserkva: SP3 – the edge of the forest in the direction of Bila Tserkva (unauthorised construction in the forests); SP5 – outskirt towards the village Volodymyrivka (landfill)

In the "Golenderna" tract of the "Olexandria" Arboretum of the National Academy of Sciences of Ukraine, the forest ecosystem degrades more intensively in the park; there is a decrease of canopy density, without undergrowth and understorey suburban strip of the massif 100–120 m wide (ruderalization and clogging of the phytocenosis; stage II of soil digression). Violations of the phytocenosis and ecological conditions of the forest environment according to the composition of xylotrophic fungi in the tract were revealed on the example of mycocenocells of the transition zone from park to forest type of landscape. As a result, 60 finds, 10 species, were identified: *Trametes versicolor* (L.) Lloyd, *H. rubiginosa*, *Stereum hirsutum* (Willd.) Pers., *V. comedens* (23 finds), *Ph. robustus* (10 finds), *Peniophora quercina* (Pers.) Cooke (7 finds), *Schizopora flavipora* (Berk. et M.A. Curtis ex Cooke) Ryvarden (6 finds), *Phellinus ferruginosus* (Schrad.) Pat. (3 finds), *Radulomyces molaris* (Chaillet ex Fr.) M.P. Christ. (3 finds), *Hyphoderma setigerum* (Fr.) Donk (1 find). These species belong to nine genera, seven families, five orders of the class Agaricomycetes of the Basidiomycota division. These xylotrophs are mainly distributed on *Q. robur* (59 finds). One find of *T. versicolor* was on trees *M. sylvestris*.

As selective sanitary felling of trees is carried out in the tract in time, there is no dryness and trees that have fallen from the wind, respectively, there is no such category of substrates. The development of carpophores *H. rubiginosa* was observed on the stumps of *Q. robur* (3.3%, butt mycohorizon; stumps without bark, d = 35 cm) and *S. hirsutum* (in cracks in the bark of stumps, d = 62 cm). It is known that the biological feature of *Q. robur* is the presence of a significant number of dry branches in the lower part of the crown due to its shading and resistance of hardwood to wind breakage. Therefore, 90.0% of finds were found on the drying branch of living trees in the crown mycohorizon: *V. comedens* (23), *Ph. robustus* (10), *P. quercina* (7), *S. flavipora* (6, on trees of Kraft classes I–IV, health condition categories II–IV), *Ph. ferruginosus* (3, trees of Kraft classes III–IV, health condition categories III–IV), *R. molaris* (3, trees *Q. robur* Kraft classes II–IV, health condition categories II–IV), *H. setigerum* (1, Kraft class I, health condition category III). The 6.7% of finds were noted in the trunk micro-horizon – *Ph. robustus* (three on whole bark and one in hollow, on trees of Kraft classes I, III, IV, health condition categories II–IV).

Suppression of forest environment conditions and mycocenocellular activity is due not only to natural but also anthropogenic factors. Thus, against the background of the dominance of saprotrophs, the contribution (prevalence) of parasites in the area is 16.7% (Fig. 2). Among the optional parasites, the dominance of *Ph. robustus* should be noted. This species is an indicator of significant transformation of oak forests.

Xylotrophs, especially saprotrophs, are mainly distributed (90.0%) on the drying branches of the lower shaded part of the *Q. robur* crowns that have health condition categories II–IV. The share of parasites in the transition zone from park to forest type of landscape is 16.7%. The most common is the indicator of significant transformation of oak forests of *Ph. robustus*. The absence of xylotrophs in the above-ground and root mycohorizons is probably caused by trampling and pyrogenic effects arising from fires not extinguished by vacationers. In the "Koshyk" tract of the green zone of

Bila Tserkva, the violation of forest vegetation conditions by the quarrying of granite due to water pumping and lowering of the groundwater level is stronger than the recreational impact on the forest. Within a radius of 70–590 m from the quarry (its depth is 80 m, area 18.1 ha), on an area of 28 ha, all *Q. robur* stands dry up and change their structure (28% of dry oak stands of the tract). Their average degradation is within a radius of 130–1580 m from the quarry, covering 72% (127 ha) of dry oak stands of the tract. Zone of weak impact (32 ha) is up to 1630 m from the quarry, on the outskirts of the forest, where the stands are weakened. Recreational soil digression also increases from stage II to stage III as the quarry approaches. It complicates the diagnosis of forest changes, their spatial zoning, the allocation of the share of a certain factor in the integral effects of changes and their mycoindication. As a result, 166 finds in the forest, 21 species of aphilophoroid fungi from 15 genera, 12 families, 5 orders of the class Agaricomycetes of the Basidiomycota division were found on four tree species: *Q. robur*, *A. platanoides*, *Crataegus oxyacantha* L. and *M. sylvestris*.

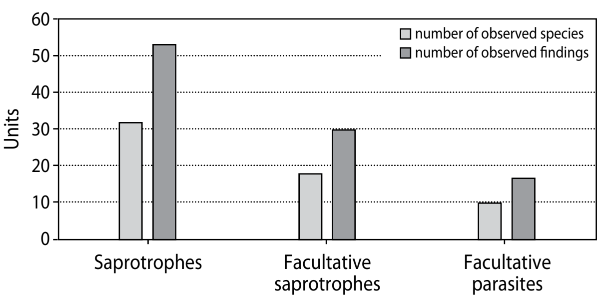

Figure 2. The ratio of trophic groups of xylotrophs of the transition zone of the Golendernya tract from the park to the forest type of landscape, Alexandria Arboretum

Xylotrophic fungi in this tract are mainly distributed in the crown horizon (75% of species and 84% of findings). Most often on *Q. robur* trees, *V. comedens* occurs (59.1% of findings), less often are *Ph. robustus* (25.2% of findings), *P. quercina* (19.1%) and *R. molaris* (15.8%). Parasitic species were found on weakened *Q. robur* trees: *F. hepatica* is found on stumps (65.2%) and shanks (34.9%) of trees; *Ph. robustus* is common on trunks (76.1%) and in tree crowns (25.3%); *Neocutis dryophila* (Berk.) (Fiasson & Niemela) occupies the trunks in severely weakened stands. In the oak stands of the green zone of Uman, 83% of fungi species and findings were concentrated in the above-ground mycohorizon; in the green zone of Bila Tserkva, on the contrary, 75%–80% of fungi species were distributed in crowns ("Koshyk" tract – 75% of species and 84% of findings; "Golenderna" tract – 80% of species and 90% of findings). This is probably due to the significant development of the shrub tier and undergrowth, greater shading of the lower part of the tree trunks, less accessibility for vacationers and in some places, pyrogenic effects.

In general, the taxonomic structure of the green zones of Kyiv, Bila Tserkva and Uman we found in the studied forest tracts is given in Table 6.

Synthesising the obtained research results, as well as the data of A.G. Medvedev (2006), we offer the following list of aphylophoroid xylotrophs, which should be used as indicators of anthropogenic transformation of forest ecosystems (* – species we identified):

Indicators of anthropogenic disturbance of oak stands and other deciduous forests

1. Severe damage to deciduous stands: *Cerioporus mollis* (Sommerf.) Zmitr & Kovalenko, 2016; *Ganoderma applanatum* (Pers.) Pat., 1889; **Phellinus robustus* (P. Karst.) Bourdot & Galzin, 1925; **Schizophyllum commune* Fries., 1815; **Stereum hirsutum* (Willd.) Pers., 1800; *Stereum rugosum* Pers., 1794; *Trametes gibbosa* (Pers.) Fr., 1838; **Trametes versicolor* (L.) Lloyd, 1920; *Bjerkandera adusta* (Willd.) P. Karst., 1879; *Daedaleopsis tricolor* (Bull.) Bondartsev & Singer, 1941; *Inonotus obliquus* (Ach. ex Pers.) Pilát, 1942; **Trichaptum biforme* (Fr.) Ryvarden, 1972; **Trametes hirsuta* (Wulfen) Pilát, 1939.
2. Average damage to deciduous stands: **Hapalopilus rutilans* (Pers.) Murrill, 1904; **Lenzites betulina* (L.) Fr., Epicrisis Systematis Mycologici, 1838; *Lentinus brumalis* (Pers.) Zmitr, 2010; **Piptoporus betulinus* (Bull.) P. Karst, 1881; **Trametes pubescens* Schumach., 1939; *Trametes suaveolens* (L.) Fr., 1838; *Cerrena unicolor* (Bull.) Murrill, 1903; **Irpex lacteus* (Fr.) Fr., 1828.
3. Low damage to deciduous stands: *Cerioporus varius* (Pers.) Zmitr & Kovalenko, 2016; **Fistulina hepatica* (Schaeff.) ex Fr., 1792; **Stereum subtomentosus* Pouzar, 1959.

Potential indicators of anthropogenic damage to coniferous forests

1. Severe damage to coniferous stands: *Sidera lenis* (P. Karst.) Miettinen, 2011; **Thelephora terrestris* Ehrh., Pl. Crypt. Linn. Exsicc, 1787; *Trichaptum abietinum* (Pers. ex J.F. Gmel.) Ryvarden, 1972; *Trichaptum fuscoviolaceum* (Ehrenb.) Ryvarden, 1972.
2. Average damage to coniferous stands: *Antrodia serialis* (Fr.) Donk, 1966; *Gloeophyllum sepiarium (*Wulfen) P. Karst., 1882; **Fomitopsis pinicola* (Sw.) P. Karst., 1881; *Postia fragilis* (Fr.) Jülich, 1982.

Indicators of mechanical damage to deciduous trees, decrease of canopy density of stands, their fragmentation, felling

**Laetiporus sulphureus* (Bull.) Murrill, 1920; **Fomes fomentarius* (L.) Fr., 1849; **Phellinus igniarius* (L.) Quél., 1886; **Leccinum scabrum* (Bull.) P. Karst., 1821; *Paxillus involutus* (Batsch) Fr., 1838.

Discussion

Abiotic ecological factors are known to significantly affect the species, taxonomic, trophic, spatial and ecological structure of xylotrophic fungi (Blinkova and Ivanenko 2014; Lavrov et al. 2017). This heterotrophic evolutionary mechanism quantitatively and qualitatively combines various processes such as tree weakening, destruction of stands, accumulation of wood waste and the rate of its decomposition by fungi into a holistic balanced process that reflects the relevant structural and dynamic characteristics of the forest ecosystem (Arefjev 2010; Blinkova and Ivanenko 2014, 2016, 2018). The analysis showed that in the last three decades, researchers were most interested in anatomical, morphological and functional indicators of the structure of the forest mycocomplex in the context of evolutionary development of forest ecosystems (Bondartseva 2004; Storozhenko 2007), as well as the co-evolution of wood-destroying fungi and forest ecosystems (Bondartseva 2004; Safonov 2003). Currently, the mycobiotic phytopathology of the forest is well developed in Ukraine (Goychuk et al. 2004). However, the issues of co-adaptation of woody plants and xylotrophic fungi are less covered (Blinkova and Ivanenko 2014), even less so are the aspects of xylomycoindication of anthropogenic disturbance of forests of different purposes (Holec 2008; Lavrov et al. 2017). In other countries, researchers usually focus on the taxonomy and floristics of xylotrophic fungi (Arefjev 2010; Safonov 2003), their diversity (Bernicchia et al. 2010; Kuffer et al. 2008a), species, trophic and formation structure of mycobiota (Bondartseva 2004; Safonov 2003), its physiological impact on trees (Boddy and Watkinson 1995; Schmidt 2006), and features of their development and distribution in different regions of the world depending on the characteristics of forests and their management (Jülich and Stalpers 1980; Kotiranta and Niemela 1996; Yurchenko 2010).

Mycoindication of disturbance of forest ecosystems is currently developed in the following directions: taking into account the sensitivity of xylotrophic fungi to changes in the environment (Blinkova and Ivanenko 2014, 2016, 2018; Holec 2008; Küffer et al. 2008a, 2008b; Lavrov et al. 2017); the use of the species composition of xylotrophs to assess the anthropogenic impact on forest ecosystems (Arefiev 2010; Medvedev 2006); and the use of the system of co-adaptation of xylotrophs with woody plants in the assessment of anthropogenic impact on forest ecosystems (Blinkova and Ivanenko 2014, 2016; Holec 2008; Kotiranta and Niemela 1996). In the context of co-adaptation of woody plants and wood-destroying fungi, special emphasis should be placed on aspects of the formation and development of their consortium relationships. On the one hand, forests are key plant communities for preserving the diversity of xylotrophs – active organisms-destroyers of plant organic matter, and destroyers of lignin and cellulose (Baldrian and Lindahl 2011; Boddy and Watkinson 1995). On the other hand, xylotrophic basidiomycetes, in particular parasitic agaricoid and aphylophoroid fungi, are the causative agents of root and stem rot, as they can worsen the health condition of stands (Mukhin and Voronin 2007). However, there are certain complications and/or limitations regarding the use of xylomycocenoses for the diagnosis of anthropogenic forest disturbances that need to be considered. Yes, not all types of xylotrophs depend on a particular tree species. Eurythrophs of the first order develop on both deciduous and coniferous species. Eurythrophs of the second order develop either on deciduous species or on conifers. Only stenotrophs develop on a certain type of tree. Not all types of xylotrophs significantly depend on the development and health condition of the tree. It should be expected that the development and spread of aphilophoroid fungi may be limited by significant changes in the forest environment and substrate stock with intensive ecosystem degradation.

In general, the results of our analysis show that the most difficult questions about the use of mycoindication in assessing the state of forests arise in the context of the combined influence of negative factors – difference in origin, distribution in time and space, modes of action and the impact on various ecosystem components. The clarification of these issues requires further research at the synecological level of analysis.

Conclusion

1. The working hypothesis on the prospects of using the species structure of xylotrophic fungi to improve the methods of assessing the nature and degree of anthropogenic transformation of the forest ecosystem, especially the health condition of stands, was confirmed. Depending on the features and degree of anthropogenic transformation of forest biotopes, the ability of 37 species of xylotrophs to be indicators of deciduous and coniferous forest disturbances is substantiated. Therefore, for mycodiagnostics, it is proposed using the most sensitive to changes in the forest environment and the health condition of the tree species of aphilophoroid fungi.
2. Xylomycocenosis is more resistant to recreational stress in contrast to the more vulnerable structural and functional components of the forest ecosystem – grass tier, undergrowth, understorey and soil surface. Therefore, close relations between the spread and development of aphilophoroid fungi and the degree of damage and drying of trees and the intensity of recreational activity could not be found. It is also not possible to detect these relations on short eco-profiles (up to 60 m). It is likely that the recreational impact is significantly neutralised due to the complex structure and large buffer capacity of the forest ecosystem, a significant number of mechanisms for its resilience, the ability to quickly regenerate degraded elements and relations of the forest.
3. Xylomycocenosis is less responsive to anthropogenic load than the above more vulnerable components of the forest ecosystem: grass and ground cover, and tree stand. Therefore, in the conditions of complex negative factors that impact the forests of different nature, targeting and spatial distribution, it is advisable to use mycoindication together with assessment of grassland digression, forest litter and soil, and stand transformation.

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