

CLIMATIC PREDICTORS INFLUENCES VFWD FUNGAL DIVERSITY THROUGH DOMINANT TREE' ECOLOGY IN BEECH FORESTS IN THE NORTH-EASTERN ROMANIA

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Abstract: Lignicolous fungi plays a vital part of forest ecosystems in Europe. They are involved in Carbon cycle, through decay processes of woody debris. Very fine woody debris (VFWD) forms an important component of this dead wood, being found in any forest in the World. Among European and Romanian forests, *Fagus* spp. dominating forests are the most important broadleaved ecosystems, of great biotic and abiotic complexity. The present distribution of lignicolous fungi is mainly linked to trees distribution. In the context of climate change, European beech forests will also shift in distribution, structure and composition, triggering changes in lignicolous fungal communities and diversity as well. Considering this background, VFWD lignicolous diversity might be a future beech forests climate change indicator. This will bring the necessity of assessing the main climatic factors that are influencing the lignicolous fungal diversity distribution across European beech forests in Romanian's North-East Region. In the present study, our findings confirms the fact that macroclimate have a great influence on lignicolous mycodiversity in beech forests. It seems that minimum temperature and Gams Continentality Index explains approximately 48% of the mycodiversity variation. While dropping minimum temperatures and increasing Gams CI values, the lignicolous fungal richness will rise. While minimum temperature of January might be linked to a complex ecological and phenological framework, Gams CI is a known ecological indicator for optimum habitat of beech forests, which in turn influence lignicolous diversity distribution. Those climatic variables might characterize the relation between plants-fungi-climate in the near future, as increasing atmospheric temperatures will manifest at different scales. Thereafter, VFWD mycodiversity might function as a valuable macroclimatic changing indicator.

Keywords: European beech, beech forests, climatic predictors, VFWD, lignicolous fungi, mycodiversity, BIO6, Gams Continentality Index.

Introduction

In the past millennia, humans have transformed the landscape, converting forests to agricultural land [FYFE & al. 2015] or changing the structure and composition of forests [ABREGO & SALCEDO, 2011]. The silvicultural practices of European forests have reduced the forest's biodiversity, including lignicolous mycodiversity through wood extraction [PREIKŠA & al. 2015] and lowering tree diversity [NGUYEN, 2015]. Forests have the ability of carbon-sequestration [WELLBROCK & al. 2017], and releasing it through deforestation leads to increasing atmospheric carbon [LISKI & al. 2000], with its known complex and negative effects, like global warming and precipitation changing [OLIVEIRA & al. 2016].

Woody debris are an important component for forest ecosystems [HEILMANN-CLAUSEN & CHRISTENSEN, 2004], as they provide developing space and nutritional resources for a variety of lifeforms, including fungi [UNAR & al. 2017]. Many studies have pointed out the importance of large woody debris [BÎRSAN & al. 2014; ZHOU & DAI, 2012], with emphasis on the log category [HEILMANN-CLAUSEN & CHRISTENSEN, 2004; HEILMANN-CLAUSEN & CHRISTENSEN, 2005], which was shown to be an indicator to forest biodiversity [UNAR & al. 2017]. Less researches have pointed out the importance of fine woody debris to the saproxylic biodiversity of forests, and especially lignicolous fungal diversity [ABREGO & SALCEDO, 2011; JUUTILAINEN & al. 2014; KRUYSS & JONSSON, 1999]. Still, FWD and VFWD may be of great diversity value for basidiomycetes, particularly in managed forests [KÜFFER & SENN-IRLET, 2004].

Lignicolous fungi are the only eukaryotic living being that are able to decay wood, through lignin degradation – the nature's most recalcitrant organic compound [KNEŽEVIĆ & al. 2013], and also the second most abundant carbon source on Earth [PALIWAL & al. 2015], and consequently introduce the nutrients back to the forest ecosystems [LONSDALE & al. 2008; BALDRIAN & al. 2016]. Besides, through the decay process carbon is released into the atmosphere [YANG & al. 2016]. Considering this, lignicolous fungi are the main trophic group among fungi in forest ecosystems [DVOŘÁK & al. 2017].

European beech is the most abundant tree species in Temperate Europe [KÜFFER & al. 2004], and especially in Central Europe [GEBER & al. 2007], and one of the most important tree species in Romania [MILESCU & al. 1967]. In Romania beech occupy large surfaces, forming pure stands or living besides coniferous or *Quercus* trees in their respective communities [MILESCU & al. 1967], in forests that occupy approximately 31% of Romania's forest territory [CÂMPU & DUMITRACHE, 2015]. In the North-East Romania, European beech is well represented, with a high presence probability in non-coniferous broadleaved forests [COPOȚ & al. 2016]. Pure beech or coniferous forests mixed with beech old-growth forests are of high value in representing European forest biodiversity [PETRITAN & al. 2012].

Even if Romania is considered a conservation hotspot for its large old-growth forests [MUNTEANU & al. 2016], which are known to host great lignicolous fungal diversity [DVOŘÁK & al. 2017], relative abundance of these forests have dropped in the past century [MUNTEANU & al. 2016]. While Romania is on 10 rank in Europe on forest ha / capita, the reforestation is gradually increasing forests surfaces [NIȚĂ, 2015].

Still, high logging rates in surrounding protected areas increase forest habitat loss and forest fragmentation [KNORN & al. 2012]. Also, harvest spikes have been observed after 2000 [MUNTEANU & al. 2016], which further increase the complex situation of Romania's forests, in terms of long-term mycodiversity conservation. As deforestation and forest disturbance are correlated with low lignicolous diversity in European broadleaved forests [BRAZEE & al. 2014], it is a sufficient trigger for assessing the status of fungal diversity.

Climate change might greatly affect European plant species distribution [THUILLER & al. 2005], including total replacement of some dominant tree species at regional scale, as in the case of European beech in Spain [PEÑUELAS & al. 2007]. In the Temperate Continental zone, forests are mainly influenced by precipitation patterns, which in the case of changing might trigger high level of water stress [LINDNER & al. 2010]. Recent decreased vigour has been observed in beech growth [AERTSEN & al. 2014], and it might be linked to precipitation pattern changing, as has been observed that both European

beech and oak are associated with negative growth depressions [SCHARNWEBER & al. 2011]. Also, recent findings [BOSELA & al. 2018] show that average beech growth declined across Europe, but this happened differently at regional scales. While in Romania, the summer drought did not influence beech radial growth, in relatively closed regions – Balkans, it did [BOSELA & al. 2018].

In the near future, predicted intensive drought periods might continue influence beech negative growth [GEBER & al. 2007] or increase tree mortality, as it is a general trend [ANDEREGG & al. 2016], which can change beech forests structure and composition [RUIZ-BENITO & al. 2013], down to the fungal composition, as fungi are highly linked to forest composition [KUTSEGI & al. 2015], but also climatic characteristics, as annual temperature and precipitations [TEDERSOO & al. 2015]. Also, natural disturbances are linked to FWD increasing [FASTH & al. 2011] and CWD increasing [BÄSSLER & al. 2016], which contribute to woody debris profile changes, and lignicolous composition [BÄSSLER & al. 2016].

Therefore, our objective is to find the climatic predictors of lignicolous fungal diversity in European beech forests across North-East Romania.

Material and methods

The North-East Region is located in the north-eastern part of Romania, occupying the Romanian part of historical province of Moldavia. It is the most forested region of all, with approximately 600,000 ha [ANDRONACHE & al. 2017]. The climate is temperate continental, but inside the region, the climatic variability is high, as multiple general and local factors interact, determining variations both of temperatures and precipitation distribution [ANM, 2008]. In general, precipitations are rising from February to July, followed by a decrease up to January [ANM, 2008].

At regional scale, precipitations are growing from southern part of the region to northern and from eastern to western part [ANM, 2008]. Carpathians presence is having a heavy effect on atmospheric mass movements, the biggest precipitations being found here [ANM, 2008]. Annual temperature varies temporal (determined by solar radiation variation) and spatially (determined by multiple factors, at different scales, e.g., elevation). The region is divided geo-morphologically in three major areas: the extra-Carpathians, the Carpathians and the transition one [MĂRGĂRINT, 2017]. For the hilly and mountain areas, annual temperature varies intra-regionally, according to altitude changing [ANM, 2008]. The mean annual temperature ranges from 0-4 °C to 10-11 °C, while mean annual precipitations in the range of approximately 1000-1200 to 500-600 mm [ANM, 2008].

A total of 25 circular plots of 1000 m² were randomly selected in North-Eastern Region, in broadleaf forests dominated by beech. Within each sample plot, all standing alive trees having a diameter at breast height (dbh) ≥ 10 cm were measured for dbh and genera was determined. A variable of beech dominance was computed the percentage of total basal area of all beech trees from the plot's total beech basal area. Afterwards, a filter was applied, and only the plots having at least 50% of beech basal area were kept, in total 23 plots (Figure 1).

The climatic variables used are representing the macroclimatic variability of beech forests in North-Eastern Romania (Table 1). All climatic variables were extracted from rasters downloaded from the cited databases, using QGIS software [Quantum GIS Development Team, version 2.18, 2017].

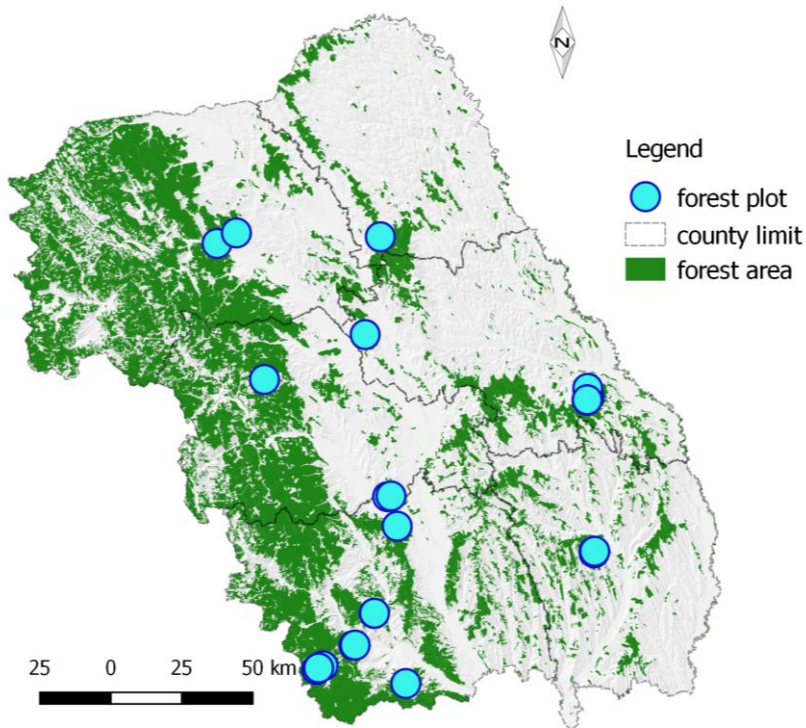


Figure 1. Plot distribution in beech forest ecosystems in North-East Romania (made in QGIS; the green forest area was obtained after ICAS Forest Type Map, 1997)

For climatic variables computing, WorldClim version 2.0 database was used at its finest resolution – 30 arcsec, equivalent to ~ 1 km [FICK & HIJMANS, 2017]. Bioclim variables and wind speed were used as *per se*, while other bioclimatic indices (e.g., water balance indexes) were derived from monthly average values for temperature and precipitations.

De Martonne aridity index (annual, seasonal, and monthly), Lang aridity index, and Koppen aridity index were selected among water balance indexes [SÁBITZ & al. 2014].

De Martonne aridity index was calculated via formula [QUAN & al. 2013]:

$AI_{DM} = MAP / (MAT + 10)$, where MAP is the annual amount of precipitations (mm), and MAT the mean annual air temperature (°C). For seasonal periods, was used formula [HRNJAC & al. 2014]:

$AI_{SDM} = 4 * P_s / (T_s + 10)$, where P_s is the seasonal mount of precipitations (mm), and T_s the mean seasonal temperature (°C). As the values decrease, the aridity grows [CROITORU & al. 2012]. For monthly periods (e.g., January and July), was used formula [HRNJAC & al. 2014]:

$AI_{MDM} = 12 * P_m / (T_m + 10)$, where P_m is the monthly mount of precipitations (mm), and T_m the mean monthly temperature (°C).

Lang aridity index or the *rain factor of Lang* was calculated as the ratio between annual precipitations and mean annual temperature [QUAN & al. 2013]:

$AI_{Lang} = MAP / MAT$, where MAP is the mean annual precipitation (mm), and MAT is the mean annual temperature (°C).

Koppen aridity index was calculated following formula [QUAN & al. 2013]:

$AI_{Koppen} = MAP / (MAT + 33)$, where MAP is the mean annual precipitation (mm), and MAT is the mean annual temperature (°C).

Potential Evapotranspiration (PET) was calculated as the sum of PET of each month, following formula [KARUNARATHNE & al. 2016]:

$PET = PET_1 + \dots + PET_{12}$, where $PET_1 - PET_{12}$ is the monthly potential evapotranspiration, which were extracted from rasters downloaded from [ZOMER & al. 2007; ZOMER & al. 2008], at 30 arc sec. From the same source** values of Global Aridity Index (GAI) were extracted.

For climatic-tree growth, *Forestry aridity index* was calculated [FÜHRER & al. 2011]:

$FAI = 100 \times T_{7-8} / (P_{5-7} + P_{7-8})$, where T_{7-8} is the average temperature of July and August, P_{5-7} is the total precipitation (mm) in May, June, and July, and P_{7-8} is the total precipitation of July and August. For beech, the optimum values are < 4.75 [FÜHRER & al. 2011].

Another beech-related index, introduced by Ellenberg is the *Ellenberg Quotient* index is calculated according to formula [VLĀDUȚ & al. 2017]:

$EQ = 1000 \times (Tw / MAP)$, where Tw is the temperature of the warmest month of the year, and MAP is the mean annual precipitations. Values bellow 20 indicate pure beech forests, between 20 and 30, favourable to beech, but excellent to oak-hornbeam woodlands, and higher than 30, mesic oak forests to dry oak forests [VLĀDUȚ & al. 2017; SALAMON-ALBERT & al. 2016].

Finally, *Gams Continentality Index* (GCI) was calculated following formula [VLĀDUȚ & al. 2017]:

$GCI = MAP / Alt$, where MAP is the mean annual precipitation (mm), and Alt is the altitude (m). If values are between 1-2 then beech is favoured [SATMARI, 2010].

Snow-related variables (Table 1) values were extracted from rasters downloaded from Lifewatch-WB ecotope database [http://www.lifewatch.be/en/data], at 500 m resolution. As snow cover influences soil moisture [POTOPOVÁ & al. 2015], it might inference with VFWD decay and mycodiversity associated.

Table 1. The potential climatic variables influencing the fungal diversity.

Climatic variable	Description	Unit
BIO1	annual mean temperature	°C
BIO2	annual mean diurnal range	°C
BIO3	isothermality	-
BIO4	temperature seasonality	%
BIO5	maximum temperature of warmest month	°C
BIO6	minimum temperature of coldest month	°C
BIO7	annual temperature range	°C
BIO8	mean temperature of wettest quarter	°C

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BIO9	mean temperature of driest quarter	°C
BIO10	mean temperature of warmest quarter	°C
BIO11	mean temperature of coldest quarter	°C
BIO12	annual precipitation	mm
BIO13	precipitation of wettest month	mm
BIO14	precipitation of driest month	mm
BIO15	precipitation seasonality	%
BIO16	precipitation of wettest quarter	mm
BIO17	precipitation of driest quarter	mm
BIO18	precipitation of warmest quarter	mm
BIO19	precipitation of coldest quarter	mm
wind	wind speed	m/s
DMAI	De Martonne aridity index (annual)	mm/°C
DMAIspr	De Martonne aridity index (spring)	mm/°C
DMAIsum	De Martonne aridity index (summer)	mm/°C
DMAIaut	De Martonne aridity index (autumn)	mm/°C
DMAIwin	De Martonne aridity index (winter)	mm/°C
DMAIjan	De Martonne aridity index (January)	mm/°C
DMAIjul	De Martonne aridity index (July)	mm/°C
LAI	Lang aridity index (annual)	mm/°C
KAI	Koppen aridity index (annual)	mm/°C
FAI	Forestry aridity index (annual)	°C/mm
EQ	Ellenberg Quotient	°C/mm
GCI	Gams Continentality Index	mm/m
PET	Potential Evapotranspiration (annual)	mm
GAI	Global Aridity Index (annual)	-
SL	snow length / average snow duration	weeks
SS	snow start	weeks
SE	snow end	weeks

Fungal data was representing by collected fruit bodies on VFWD (Very Fine Woody Debris), defined as the woody debris with a diameter at large head between 1 and 5 cm. The lignicolous fungal species were detected at species or genera level, using literature [SĂLĂGEANU & SĂLĂGEANU, 1985; BREITENBACH & KRÄNZLIN, 1986; RYVARDEN, 1991; GERHARDT, 1999; BERNICCHIA, 2005; TĂNASE & al. 2009; COURTECUISSÉ & DUHEM, 2013]. The fungal nomenclature used was based on Index Fungorum [<http://www.indexfungorum.org/Names/Names.asp>].

The full variables set was tested for collinearity, using Spearman correlation $|r| > 0.7$. The 8 uncorrelated variables and the mycodiversity data were used to select the best models according to BURNHAM & ANDERSON (2002). This method uses the Akaike's information criterion (the delta AICc < 2), to find the best variables combination that explains the mycodiversity variation [BURNHAM & ANDERSON, 2002]. For the delineation of the best model we choose the adjusted R^2 with the largest value. For the final form of the model, we used the polynomial form of variable – diversity relation.

For statistical analyses, we used R version 3.4.0 software [R Development Core Team, 2005] with the packages *base*, *data.table*, *MuMIn*, *reshape*, *rsq*. Predictor's relations with mycodiversity were visualized using 2'nd degree polynomials plotting with PAST software [HAMMER & al. 2001].

Results and discussions

We recorded a total of 110 fungal taxa (in ca. 450 records). The species belongs to 84 genera, 46 families, 29 orders and 2 phyla. The taxa was distributed uneven, with Basidiomycota phylum dominating (66.4%), while Ascomycota taxa were lesser (33.6%). The most rich families (Figure 2) were Polyporaceae (10 taxa), Xylariaceae (7 taxa), Mycenaceae (7 taxa), Diatrypaceae (6 taxa), Hypoxylaceae (6 taxa), and Inocybaceae (6 taxa).

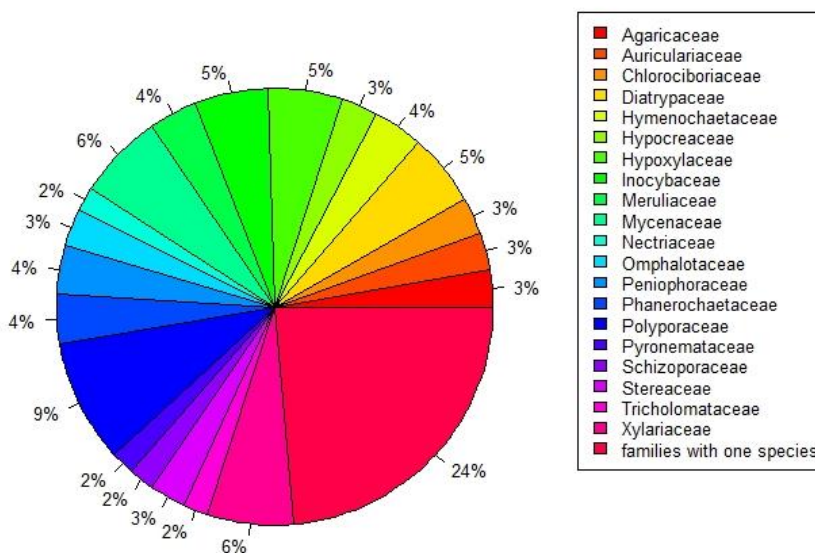


Figure 2. Families richness of lignicolous fungi found on VFWD in beech-dominated forests

The fungal lignicolous taxa varied from 7 to 25, with the mean of about 15 species. The most found species were: *Diatrype stigma* (82%), *Stereum hirsutum* (73%), *Biscogniauxia nummularia* (65%), *Schizophyllum commune* (60%), *Hypoxylon fragiforme* (60%), *Diatrype disciformis* (48%), and *Cerioporus varius* (48%). Taxons found only once

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are representing approximately 52% of the diversity. Some of these are ubiquitous in broadleaved forests (*S. commune*, *D. stigma*, *S. hirsutum*) [TĂNASE & al. 2009].

Other (*B. nummularia*, *H. fragiforme*, *C. varius*) are specific to beech forests, as beech wood colonizers, in Hungary [KUTSEGI & al. 2015] or Romania [TĂNASE & al. 2009]. In Spain [ABREGO & SALCEDO, 2011], *D. disciformis*, *H. fragiforme*, *B. nummularia*, and *S. hirsutum* were also found frequently on beech wood. On beech VFWD, the fungal diversity represented 75% and had a 0.94 Spearman correlation with total diversity.

Through Burnham & Anderson analysis, we obtained 2 models that best explains the lignicolous fungal diversity (Table 3). The variables found were: BIO6 (minimum temperature of the coldest month) and GCI (Gams Continentality Index). According to the highest adjusted R², the best model was formed from BIO6, GCI and BIO12 (mean annual precipitations), together explaining 50.5% of lignicolous fungal diversity variability on VFWD in European beech dominated forests in North-Eastern Romania.

Table 2. Characteristics of final variables used in lignicolous mycodiversity.

Climatic variable	Importance	P-value <0.05	adj-R ²	Min	Max	Mean	Sd
BIO6	0.769	0.001	0.39	-8.40	-6.10	-7.33	0.45
GCI	0.676	0.02	0.22	0.83	1.98	1.35	0.05
BIO12	0.379	0.14	0.05	531	605	561.4	23.2
BIO11	0.319	0.07	0.14	-2.42	-0.70	-1.53	0.33
BIO2	0.307	0.35	0.04	8.09	9.08	8.46	0.31
DMAIwin	0.233	0.06	0.11	30.9	45.3	36.4	4.50
wind	0.199	0.40	0.03	2.2	3.2	2.7	0.28
SL	0.191	0.32	0.04	3	18	~11	4.69

GCI and BIO6 were statistic significant, while BIO12 was not found significant (Table 2). Thus, the final model was composed only from the two variables, which were also determined as the most important predictors for lignicolous fungal richness on VFWD in European beech forests, while explaining 48% of variation. Adding BIO12 (mean annual precipitations), the explaining power riches approximately 50%, thus having a little influence to interpret mycodiversity variation.

Table 3. Best explaining models of macroclimatic influence on lignicolous fungal diversity in beech-dominated forests.

Intercept	BIO11	BIO12	BIO2	BIO6	GCI	DMAIwin	SL	wind	R ²	AICc	delta	weight
-1.939	-	-	-	-0.55	0.365	-	-	-	0.70	136.07	0.0	0.68
-3.228	-	0.0029	-	-0.50	0.398	-	-	-	0.72	137.59	1.5	0.31

In Romania, recent spatial modeling [COPOT & TĂNASE, 2017] of another broadleaved forests-specific lignicolous fungal species – *Ganoderma lucidum*, found that elevation was the most important abiotic factor influencing its distribution in the same area.

Elevation is a proxy for temperature and precipitations [VAN GILS & al. 2012]. Particular bioclimatic variables – including mean average temperature (BIO1), mean precipitations (BIO11), and minimum temperature (BIO6) – were correlated with elevation, in North-Eastern Region [COPOȚ & TĂNASE, 2017]. It is clear that temperature influences the distribution of some lignicolous fungi in temperate broadleaved forests.

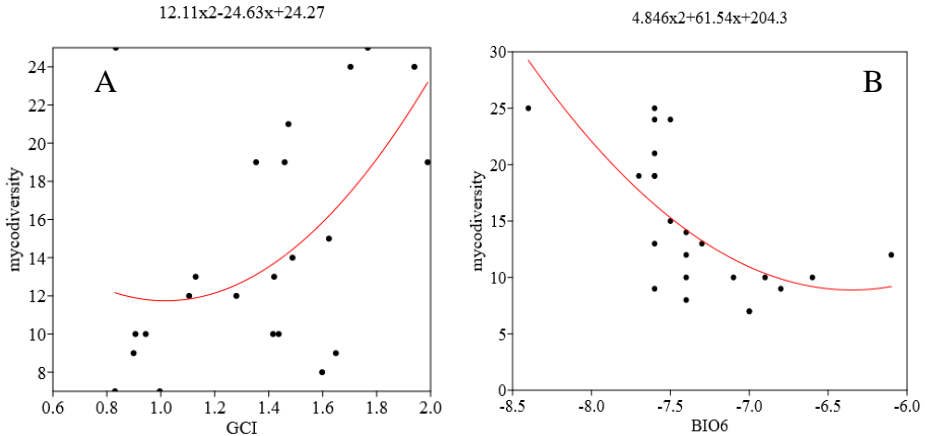


Figure 2. Graphic representation of the relations between fungal lignicolous diversity and: (A) Gams Continentality Index (GCI); (B) Minimum temperature of the coldest month (BIO6).

We found high lignicolous fungal diversity in plots where the Gams Continentality Index (GCI) was high. From Figure 2 (A), it can be seen that, as the GCI grows so is the mycodiversity. From the GCI interpretation, values below 1 shows stands where coniferous trees are favored, values between 1 and 2, are favorable to beech, and above 2, where thermophilous trees grows [SATMARI, 2010].

Approximately 74% of the plots were in a habitat favorable to beech. Consequently, starting from mixt beech-coniferous forests to beech optimum, the mycodiversity is growing. Optimal beech stands are associated with thick litter [MILESCU & al. 1967]. But high tree litter layer is associated with thermic amplitude decrease and reduced number of frost days [LOYDI & al. 2014]. Also, it keeps humidity on larger time periods [MILESCU & al. 1967]. Soil and litter high moisture have been linked to fungal mycelial spreading [KALUCKA, 1995; KUBARTOVÁ & al. 2009]. The thick-litter conditions creates a more stable microclimate, which will not permit to specialized pioneer fungi to engrossment the substrate for themselves. This assumption is confirmed by the well-known situation of above-ground VFWD, which have an instable microclimate, and therefore, particular fungal lignicolous species, with xeric adaptations to colonize the wood [HEILMANN-CLAUSEN & CHRISTENSEN, 2003].

Still, because many VFWD pieces are integrated in the litter, in the advanced stages of decay [OSTROGOVIĆ & al. 2015], a higher litter thickness will increase the chances of wood hindering. This process is influenced by multiple factors, as it is a multiannual process – beech FWD being found to full decay in approximately 18 years in Germany [MÜLLER-USING & BARTSCH, 2009]. Unlike above-VFWD, under- or partially buried VFWD will have a greater moisture, as the larger soil-contact is associated

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with higher moisture [HEILMANN-CLAUSEN & CHRISTENSEN, 2003]. Another aspect shows that a higher surface-to-volume ratio – which characterize the VFWD [HEILMANN-CLAUSEN & CHRISTENSEN, 2004] – is increasing even furthermore the wooden surface-to-litter surface ratio. This means that litter-integrating VFWD will likely offer preferential conditions for fungal colonizing from a 3D-spatial context.

A question might be asked here: If the VFWD turnover is fast, than why the lignicolous diversity is still higher? The answer resides in the capacity of a humid and wood-rich litter to offer development space for grazing mycelium. Saprotrophic fungi are known for their capability to develop a net-like mycelium that will forage the substrate for water and nutrients [WEBSTER & WEBBER, 2007].

Even if fungi produces strong extracellular enzyme in order to decay organic material, these enzymes lack the ability to diffuse at large distances [PETRE & al. 2014]. Thereafter, the fungus must expand into the newly found wood substrate [PETRE & al. 2014], and thus, if the conditions permit, to develop reproductive mycelia. In turn, this will increase the chances of spore colonizing in the area, with increasing mycodiversity.

Observing the trend of the GCI-diversity relation (Figure 2), even if the GCI values are constantly growing, the mycodiversity will do the same. This triggers another question, whether the fungi are developing well in other beech forests, which have thermophilic tree species in them, like oaks and hornbeam.

In this case, some species will change the wood genera host, while others will be replaced by newly tree genera. High-GCI stands have genera (e.g., *Tilia*, *Acer*, *Quercus*) with numerous known associated lignicolous fungal species [GERHARDT, 1999; RYVARDEN, 1978; SĂLĂGEANU & SĂLĂGEANU, 1985; TĂNASE & al. 2009] that grows furthermore the beech forest's diversity.

While the first factor was characterizing the water balance of beech ecosystems, the second one is a measure of temperatures. European beech is sensible to low temperatures, both saplings and spring buds [BOLTE & al. 2007; MILESCU & al. 1967]. According to authors [BOLTE & al. 2007], the following values are necessary to fulfill the minimum winter temperatures requirements: January mean temperature above -3°C, at most 148 days with daily mean temperature less than 7°C, no severe winter frosts (<-35°C) or severe late frosts.

Among this beech distribution factors, BIO6 (minimum temperature of the coldest month) which in this case is January, have been proved to significantly negative influence the lignicolous fungal diversity in *Fagus* dominated forests.

In the context of high trunk water content and winter temperature very suddenly dropping, frost cracks appears on beech trunk [CÂMPU & DUMITRACHE, 2015]. While the shallow cracks heal from year to year, the deep ones will not (every year, the cracks are re-opening), which will maintain a “proper” access to saproparasitic fungi [CÂMPU & DUMITRACHE, 2015]. Considering that beech have little resistance to strong winds [MILESCU & al. 1967], the frost cracks weakens even more the beech's standing. In time, the tree will dry and die, enriching constantly the downed woody debris pool. A higher dead wood on the soil will likely be correlated with higher lignicolous mycodiversity, as is proven that wood volume is well related with species richness [HEILMANN-CLAUSEN & CHRISTENSEN, 2004; KLOCKOW & al. 2014; LASSAUCE & al. 2011].

Another aspect consists in the beech saplings' sensitive to winter frosts, approximately 50% of beech saplings being killed by temperatures between -17 and -21 °C [BOLTE & al. 2007]. Following this, in the spring, other tree species might take the

initiative and properly install in beech forests, where the canopy gap is large enough. In time, this will increase stand tree diversity, which have been linked to macrofungal richness [BUÉE & al. 2011].

In harsh-winters areas (delineated here by BIO6 low values), any fallen branch will enlarge the VFWD and FWD pool on the ground, without the possibility for lignicolous fungi to decay the wood, as low temperatures are known to hinder wood decay [KUBARTOVÁ & al. 2009]. On the contrary, mild-winters areas (BIO6 high values), the decay process is less discontinued during January, which continues wood decay. In the spring, higher temperatures and humidity might start a fast wood fungal colonization, as higher humidity and rising temperatures are associated with faster decay rates [FRAVOLINI & al. 2018].

Living wood has a higher concentration of nutrients in the winter – as a resource for spring sprouting –, and VFWD a higher nutrient concentrations than CWD [KLOCKOW & al. 2014]. Therefore, in harsh-winter stands, any fallen wood, will enlarge the resource availability for new and multiple colonizers, in the spring, more than areas with mild-winters. Starting the spring with an already installed community, the fungal richness might be lower than in the mild-winter stands, which in contrast, has an explosion of diversity. Consequently, because of good resources available, in the following spring and summer, newly installed fungal colonizers will be more diverse, increasing the overall VFWD mycodiversity.

Finally, beech is also sensitive to late frosts, which heavily affect seedlings and buds [MILESCU & al. 1967]. Afterwards, the trees are able to come back and form a new canopy, but at the expensive of fructification in that respective year [MILESCU & al. 1967]. This in turn, leaves the stand without a beech seedling year, which makes room for other's tree species' seedlings. The effects is the same as previous mentioned, with increasing tree diversity in time.

This hypothesis is sustained by the phonological temperament of beech, which starts sprouting earlier than other trees, especially on the lower part of slopes [MILESCU & al. 1967]. Usually, the lowest values of minimum January temperature are found in depressionary areas, valley corridors and high elevations, the North-Eastern part being associated with the a high number of days with frost [ANM, 2008].

Also, in mild-winter stands, beech starts sprouting and forming a canopy earlier, as the growing season has a larger number of days. The newly created shade will maintain humidity at soil level, but in the harsh-winter stands, the fact that canopy-derived shading is delaying might offer greater access to solar radiation, and warm up the litter and VFWD. Still, temperature droppings can occur in the early spring. This situation might trigger the cold-shock effect in lignicolous fungi, as some species initiated fruiting [PINNA & al. 2010]. Also, species from one group in particular – Ascomycota – are growing in the late-winter and spring [RUDOLPH & al. 2018]. On short-term, mycodiversity will increase, based on ascomycetes, which, according to a recent study can form up to 51% of total diversity [RUDOLPH & al. 2018].

Increasing temperatures will permit not only the colonization of new wood via spore germination, but also mycelial growth from one piece to another. The fact that lignin represent approximately 20% of plant litter in forests [PALIWAL & al. 2015], and VFWD density is higher than logs, that means that there is a greater chance for spreading mycelium to find a new substrate and colonize it, at least for the lignicolous fungi that prefer this type of colonizing strategy.

Conclusions

In conclusion, the lignicolous fungal diversity is influenced by macroclimatic characteristics. The mycodiversity is rising with minimum temperature dropping and with aridity index rising. The availability of good thermo-humid conditions is crucial for high lignicolous fungi diversity in European beech forests from North-Eastern Romania. This study shows that macroclimate is of great value in determining lignicolous fungal richness at regional scale. Also, the mycodiversity found in beech-dominated forests, are closely linked to the relation between the main host tree species and its ecological behavior. Therefore, macroclimatic characteristics must be included in diversity studies, even on very fine woody debris, which are often rejected from mycodiversity studies, even if this wood type represents the most ubiquitous downy wood component in forest ecosystems across the world.

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