Attachment No 4a

Summary of Professional Accomplishments

Dr. Leszek Karliński

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1. Name

Leszek Antoni Karliński

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2. Diplomas, degrees conferred in specific areas of science or arts, including the name of the institution which conferred the degree, year of degree conferment, the title of the PhD dissertation

14.06.2007 – doctor of biological sciences in the field of biology, Institute of Dendrology of the Polish Academy of Sciences in Kórnik, the title of doctoral thesis: The communities of ectomycorrhizas of Norway spruce and soil microorganisms in mature forests, supervisor: prof. dr. hab. Barbara Kieliszewska-Rokicka, reviewers: prof. dr. hab. Hanna Dahm, prof. dr. hab. Stanisław Pukacka

3. Information on employment in research institutes or faculties/departments or school of arts

1.08.1996 – 30.09.1996: Wielkopolska Oncology Centre, position: medical technician

1.09.2001 – 15.12.2001: Institute of Dendrology, Polish Academy of Sciences, contract of mandate

21.01.2003 – 18.07.2003: *Danish Institute of Agricultural Sciences,* Department of Integrated Pest Management, Research Centre Flakkebjerg, Danish Government Scholarship, an internship during PhD studies

1.07.2006 – 10.09.2006: Institute of Dendrology, Polish Academy of Sciences, contract of mandate

16.10.2006 – 27.11.2006: Institute of Dendrology, Polish Academy of Sciences, contract work

18.09.2007 – 12.10.2007: Institute of Dendrology, Polish Academy of Sciences, contract work

2.11.2007 – 15.12.2007: Institute of Dendrology, Polish Academy of Sciences, position: biologist

16.12.2007 – 15.01.2008: Institute of Dendrology, Polish Academy of Sciences, contract work

15.01.2008 – 31.05.2008: Institute of Dendrology, Polish Academy of Sciences, position: biologist

1.06.2008 – 30.03.2010: Institute of Dendrology, Polish Academy of Sciences, position: biologist

31.03.2010 – 29.08.2019: Institute of Dendrology, Polish Academy of Sciences, position: biologist

30.03.2011 – 29.07.2011: unpaid leave in IDPAS; Aarhus University, Faculty of Agricultural Sciences, Department of Integrated Pest Management, Flakkebjerg, Danish Government Scholarship, post-doctoral internship

30.08.2019 – to date: Institute of Dendrology, Polish Academy of Sciences, position: assistant professor

4. Description of the achievements, set out in art. 219 para 1 point 2 of the Act

The title:

Impact of tree host genotype and environmental conditions on the soil microbial community of poplars

Field of sciences: Natural sciences

The discipline of sciences: Biological sciences

List of publications contributing to the achievement:

- **Karliński L**, Rudawska M, Kieliszewska-Rokicka B, Leski T. 2010. Relationship between genotype and soil environment during colonization of poplar roots by mycorrhizal and endophytic fungi. Mycorrhiza 20, 315-324.

  (IF_{2010} = 2,571, $MNiSW_{2010}$ scoring = 32 pts.)

  My contribution to this work consisted of participation in the development of the research concept and preparation of the final research model of studies; samples collection in the field; carrying out all of the analyzes in the lab; analysis of the results; writing the initial version of the manuscript and correction of the manuscript after reviews. I estimate my participation in the preparation of this publication at 82%.

- **Karliński L**, Rudawska M, Leski T. 2013. The influence of host genotype and soil conditions on ectomycorrhizal community of poplar clones. European Journal of Soil Biology 58, 51-58.

  (IF_{2013} = 2,146, $MNiSW_{2013}$ scoring = 25 pts.)

My contribution to this work consisted of preparation of the research model of studies; sample collection in the field; carrying out all of the analyzes in the lab; analysis of the results; writing the initial version of the manuscript and correcting the manuscript after reviews. I estimate my participation in the preparation of this publication at 90%.

- **Karliński L**, Ravnskov S, Rudawska M. 2020. Soil microbial biomass and community composition relates to poplar genotypes and environmental conditions. Forests 11, #262.

  (IF2020 = 2,633, $MNiSW_{2020}$ scoring = 100 pts.)

  My contribution to this work consisted of preparation of the final research model of studies; samples collection in the field; carrying out all of the analyzes in the lab; analysis of the results; writing the initial version of the manuscript and correcting the manuscript after reviews. I estimate my participation in the preparation of this publication at 88%.

- **Karliński L.** 2021a. Biomass of external mycelium of mycorrhizal fungi associated with poplars – the impact of tree genotype, tree age and soil environment. Applied Soil Ecology 160, #103847.

  (IF2020 = 4,046, $MNiSW_{2020}$ scoring = 140 pts.)

- **Karliński L.** 2021b. The arbuscular mycorrhizal symbiosis of trees. Structure, function and regulating factors. W: Shrivastava N., Mahajan S., Varma A. (red.) Symbiotic Soil Microorganisms. Biology and Applications. Springer. 117-128.

  (IF2020 = - MNiSW scoring = 20 pts.)

Scientific achievement is a series of original published scientific publications in 2010-2021 in journals in the Journal Citation Reports database and the book chapter. The total Impact Factor (consistent with the year of publication) of these items is 11,396 and the total number of points from the Ministry of Science and Higher Education is 430.

INTRODUCTION

Poplars have been an important biotic element of the natural and transformed landscape. The genus *Populus* (Salicaceae), comprise approximately 40 species widely distributed over the northern hemisphere from the tundra to North Africa (Bugała 1973). To this day, new poplar species are still being discovered, and the last of them *Populus primaveralepensis* sp. Nov. was identified in 2019 in the forests of the state of Jalisco in western Mexico (Vázquez-García et al. 2019). The exact number of species is difficult to estimate also due to the ease of interspecific crossing of poplars (Bugała 1973; Eckenwalder

et al. 1996). On the one hand, this feature is an advantage and has been used by humans for a long time. It resulted in the creation of a large number of hybrids and clones, often showing significant differences in terms of morphological and physiological features, including tolerance of the biotic and abiotic stresses, such as the impact of drought, contamination with heavy metals, etc. (e.g. Sebastiani et al. 2004; Laureysens et al. 2005). On the other hand, the ease of interbreeding of poplars poses a serious threat to local, natural sites, e.g. the black poplar (*Populus nigra* L.), which is replaced over time by spontaneously formed hybrids with foreign, mostly American, cultivated species of poplars (Tylkowski 2010).
In natural conditions poplars as light and moisture-loving trees often grow along watercourses and in riparian forests. During the floods poplars and alders have been playing an important role as a buffer zone, limiting the negative effects of inundation. The regulation of rivers and land drainage for agriculture has led to the destruction of most natural habitats of native poplars, resulting today in the strong need to undertake extensive restoration works (Zsuffa et al. 1996; Smulders et al. 2008). Due to such features as rapid growth and production of biomass, ease of vegetative reproduction through cuttings, or tolerance to unfavourable environmental conditions, poplars, apart from their natural, cultural and aesthetic functions (**Karliński 2020b**), have been used in agriculture, forestry (afforestation of post-agricultural or degraded post-industrial areas), as well as in various branches of the wood, paper, or chemical industry and bioenergy production. After WW2 poplars were also planted willingly in urban conditions to quickly rebuild the green garment of cities and to improve the urban microclimate with these so-called oxygen trees accumulating significant amounts of carbon dioxide and producing oxygen (e.g. Sebastiani et al. 2004; Yin et al. 2005; Monclus et al. 2006; Langer et al. 2012). Perennial poplar plantations can also play a significant role in increasing the organic carbon content of the soil and in mitigating the impact of climate change (Zheng et al. 2017). These multipurpose characteristics of poplars have been mirrored in numerous studies and selective breeding programmes (Bradshaw et al. 2000), and have resulted in poplars becoming model plants. The first tree whose genome was sequenced was *Populus trichocarpa* (Tuskan et al. 2006).
To date, several studies of poplars and their genetic diversity have focused on the above-ground part of trees and their response to environmental factors. Much less attention was paid to their underground part and their relationships with other groups of organisms. Over recent years have poplars gained greater recognition as model organisms in the studies of interactions between plants and soil microbiota (Cregger et al. 2018).
The soil microbiome and mycorrhizal fungi play a key role in water and nutrient uptake, pathogen protection pollutant immobilization and other processes observed in the terrestrial ecosystem (Gotel et al. 2011; Shakya et al. 2013; Beckers et al. 2017; Chodak et al. 2013). The structure of the communities of soil microorganisms accompanying plants and their biomass are sensitive indicators of changes in soil fertility (Peacock et al. 2001), the composition of plant communities (van der Heijden et al. 2008), deposition of various types of compounds in the soil (Stephen et al. 1999), or climate changes (Zogg et al. 1997). Plants, as primary suppliers of carbon exudates and other plant-derived materials, may also significantly affect the soil microbiome (Bulgarelli et al. 2015; Lottmann et al. 2010; Schweitzer et al. 2008).

Compared to others, poplars are very interesting trees, because of their ability to establish symbiotic relationships both with arbuscular and ectomycorrhizal fungi. Only a small group of tree species apart from poplars (e.g. *Salix*, sp., *Alnus* sp., *Quercus rubra*, some species of *Carya*, as well as more exotic *Acacia* sp., *Eucalyptus* sp., *Casuarina* sp., *Uapaca* sp. or Myrtaceae) can co-create symbiotic relations with two so different in terms of the history of evolution and morpho-anatomical and physiological features groups of fungi (Lodge 1989; Neville et al. 2002; Gehring and others 2006; **Karliński et al. 2010**; **Karliński 2021b**).

Arbuscular mycorrhiza is the most common type of symbiotic association of plants and fungi, occurring in more than 71–90% of vascular plant species. This type of mycorrhiza co-created by fungi belonging to the phylum Glomeromycota (Smith and Read 2008; Błaszkowski 2012) dominates in tropical forests. In the temperate zone, along with poplars and other representatives of the Salicaceae, it is also characteristic for trees and fruit shrubs (eg maples, ash, chestnut and elm trees). Moreover, arbuscular mycorrhiza is present in the roots of grasses (including cereals), maize, strawberries, potatoes, garlic and onions (Karliński et al. 2021b). It is also evolutionarily the oldest type of symbiosis of plants and fungi, which could probably accompany plants during their colonization of the terrestrial environment or just after that, strongly supporting the rapid colonization of lands (Delaux 2017; Chen et al. 2018).

Arbuscular mycorrhiza could appear in plant tissues over 450 million years ago in Ordovician (Brundrett 2002). However, problems with the interpretation of these findings mean that the first well-preserved fossils of mycorrhizal rhizomes are structures similar to modern counterparts from early Devon, whose age is estimated at 407 million years old. The Devonian land plants revealed the presence of mycorrhiza-like intracellular structures similar to arbuscules of Glomeromycotina and hyphae reminiscent of Mucoromycotina, having the same ancestor somewhere between 358 and 508 million years ago (Martin et al. 2017). On the other hand, molecular data indicate that the symbiotic relationship between fungi and plants may be much older than their presence on land (Brundrett 2002; Martin et al. 2017). Symbiosis of plants and fungi was developing or disappearing with the radiation of plants and under the impact of often rapid climatic changes taking place in the terrestrial environment. The presence of arbuscular mycorrhizal structures has been found, among others, in woody plants of Lepidodendron and Cordaites – the conifer ancestors over 300 million years ago in late Carboniferous (Martin et al. 2017). Then the symbiotic relationships of plants with arbuscular fungi were developed in gymnosperms cycads and conifers and had been constituted the main form of mycorrhizal symbiosis from Triassic to Cretaceous. In the early Cretaceous about 145 million years ago, the symbiosis with arbuscular fungi was also established in angiosperms, early monocotyledons and dicotyledons. Most of the arbuscular symbiotic relations, which were formed in the roots of herbaceous plants at that time, have reminded unchanged to this day (Martin et al. 2017, Brundrett and Tedersoo 2018).
Earlier, in the Jurassic and early Cretaceous (140 - 180 million years ago), an ectomycorrhizal symbiosis for the first time evolved from arbuscular mycorrhiza, establishing a relationship with early Pinaceae in semi-arid regions in tropical and subtropical climates. The temperature drop in the Cenozoic favoured the presence of ectomycorrhizae in the coniferous forests of that time and in angiosperms plants. Ectomycorrhizal symbiosis has evolved many times,

most probably from its saprotrophic fungal ancestors, in many independent development lines of both plants and fungi (Martin et al. 2017; Brundrett and Tedersoo 2018).
The next wave of evolutionary changes in the Cretaceous (about 100 million years ago) also gave rise to new types of symbiotic and not only mycorrhizal compounds with species belonging to the Orchidaceae, Ericaceae, parasitic and carnivorous plants, or associated with nitrogen-fixing bacteria (Brundrett 2002; Brundrett and Tedersoo 2018; Martin et al. 2017).
Over the last 65 million years (Palaeogene), another wave of radiation mainly affected previously arbuscular species, and as a result of ectomycorrhizal and non-mycorrhizal speciation, which was mainly conditioned by climate change and an increase in habitats and their complexity. In most lines plants have evolved from relations with arbuscular fungi to ectomycorrhizal symbiosis, present today in 2% of vascular plants that enter into symbiotic relationships with fungi belonging to the groups Ascomycota and Basidiomycota (Brundrett 2017). Most of the ectomycorrhizal plant species are present in the temperate and boreal zone. Ectomycorrhizal trees are the main forest species including coniferous species like pine, spruce, fir and deciduous beech, hornbeam, birch and oak. As already mentioned, a group of trees (including Poplars) has also developed symbiotic relationships with both arbuscular and ectomycorrhizal fungal groups.

The terrestrial environment, characterized by a significant diversity and frequent changeability of atmospheric conditions, is the dominant factor affecting the communities of microorganisms associated with the root system of trees. In the case of mycorrhizal fungi, environmental conditions determine both their global distribution, ranging from rich, species-diverse tropical forests which are the optimal habitat of arbuscular mycorrhiza to less diverse and poorer in nutrients forests of the northern hemisphere, characterized by a much slower circulation of nutrients than in the tropics, and dominated by ectomycorrhiza (Gonçalves and Martins-Loução 1996; Smith and Read 2008; Karliński et al. 2010, 2013, 2020). The differences between these two symbiotic fungal groups (arbuscular and ectomycorrhizal fungi) are especially visible in the case of poplars and other tree species that interact with arbuscular and ectomycorrhizal fungi simultaneously. As the first, the symbiotic relations are established with arbuscular fungi, which are partially replaced over time by ectomycorrhizal fungi (Dominik 1958; Smith and Read 2008). From my observations being part of the presented achievement as well as based on other works with various clones and poplar hybrids, it appears that this process is very dynamic and after a few months, fully developed structures of ectomycorrhizal fungi are visible on the roots of young seedlings. At the early stage of the growth of poplars, most ectomycorrhizas belong to Ascomycota (80%). The contribution of fungi belonging to Basidiomycota in these communities increased with the age of plants (Smith and Read 2008; Karliński, unpublished data). The process of root colonization of young seedlings by symbiotic fungi may be significantly accelerated by the presence of mature arbuscular trees in the vicinity of seedlings (for arbuscular fungi) and ectomycorrhizal trees in the case of ectomycorrhizal fungi (Dickie et al. 2001). Arbuscular fungi are known for their higher tolerance to adverse environmental conditions than ectomycorrhizal fungi (Smith and Read 2008). During the dual fungal colonization of roots, arbuscular fungi tend to partially migrate into deeper soil layers, characterised by the limited availability of oxygen and nutrients. Ectomycorrhizal fungi predominate on the roots in the upper soil layer, characterised by more optimal conditions (Neville et al. 2002; Karliński et al. 2010). Wet and poorly aerated soils are less stressful for arbuscular fungi than for ectomycorrhizal fungi which prefer lighter and more well-drained soils. Therefore, during floods or in wetlands, the contribution of ectomycorrhizal fungi in the colonization of fine roots was decreasing e.g. for *Alnus* (Truszkowska 1953), *Populus, Salix* (Lodge 1989) and *Quercus rubra* (Watsoni et al. 1990). Similarly, drought stress decreases the symbiosis of both groups of fungi, however arbuscular mycorrhiza presents higher tolerance for water deficit and this type of symbiotic association is more common in arid and semi-arid conditions (Gehring et al. 2006; Quereyeta et al. 2009; Kilpeläinen et al. 2017). Forest fires also reduce the ectomycorrhizal inoculum to a greater extent than that of arbuscular fungi, which are able more quickly support the regeneration of damaged areas (Lapeyrie and Chilvers 1985; Horton et al. 1998; Teste et al. 2019). High temperatures generally do not favour ectomycorrhizal fungi (McGee 1988). On the other hand, low temperature is one of the factors limiting the occurrence of arbuscular fungi, but not the ectomycorrhizal type of symbiosis, which dominates in the northern part of the globe (Kilpeläinen et al. 2016). The distribution of symbiotic fungal types is also conditioned by the nutrient abundance in soil. Arbuscular fungi prefer rich soils, and the phosphorus content is the limiting factor for them, while the ectomycorrhiza symbiosis is usually present in poorer soils with nitrogen content as a limiting factor. (Baum and Makeschin 2000). The element of soil pollution with heavy metals as a factor conditioning the mycorrhizal symbiosis and other groups of fungi (root fungal endophytes), bacteria and protozoa, was taken up in the publications included in the presented achievements.

The role of tree genotype in shaping microbial communities has not been widely studied so far, and most studies have focused on short-lived crop plants, e.g., barley, tomato, cucumber, sweet pepper, chickpeas (Bulgarelli et al. 2015; Ellouze et al. 2013; Ravnskov et al. 2016) or trees at the early stage of growth (Gamalero et al. 2012). Little is known about how the extent to which the genotype of perennial plants, such as trees, affects different groups of the soil microbiome after many years of growth under different soil conditions (Fernández-González et al. 2019). For some poplars, e.g., *Populus angustifolia* and their F1 generations and back hybrids, Schweizer et al. (2008) showed a significant influence of the genotype of trees on the total biomass of soil microorganisms. But, for example, the studies of *Populus fremontii* conducted by the same authors did not confirm these observations. The role of the host genotype in shaping the communities of microorganisms present in various tissues of trees, i.e. in the roots, trunk and leaves, was pointed out by Gottel et al. 2011; Cregger et al. 2018; Bonito et al. 2019. Its composition may be significantly different in relation to the tree rhizosphere microbiome (Gottel et al. 2011; Beckers et al. 2017; Cregger et al. 2018; Bálint et al. 2013). Corredor et al. (2014), Gehring et al. (2006), Ghergel et al. (2014) or Tagu et al. (2001). Most of the cited studies suggest the influence of the tree genotype on the recruitment of ectomycorrhizal fungi by controlling the amount and composition of exudates released into the soil (Bakker et al. 2012). Unfortunately, there is still relatively little data on the effects of the tree genotype on microorganisms other than ectomycorrhizal fungi in the soil environment and on the interrelationship between their different groups.

THE AIMS OF THE STUDIES

The main objective of the study was to determine whether internal (tree genotype) and external (soil environment) factors significantly determine the development of poplar fine roots and associated communities of mycorrhizal fungi and other soil microorganisms.

The second objective was to estimate the extent to which the above-mentioned factors affect the soil microbiome of poplars and the qualitative and quantitative relationships of its microorganisms.

Individual publications included in this achievement focused on the analysis of the impact of tree genotype and environmental factors (with particular emphasis on soil depth and heavy metal contamination) in different zones of tree-microbiome interactions, starting from fine roots and their colonization by mycorrhizal fungi and fungal root endophytes, through the qualitative composition of ectomycorrhizal fungal communities, to the biomass and qualitative composition of microbial communities present in the rhizosphere and the bulk soil.

STUDY SITES

The studies included in the presented achievement were conducted based on four selected genotypes/clones of poplars, i.e. *Populus deltoides* (clone S-1-8 "DUNAV"), *Populus deltoides* × *Populus nigra* (clone 490-1), *Populus deltoides* × *Populus trichocarpa* ("DONK" clone) and *Populus maximowiczii* × *Populus trichocarpa* (NE-42 clone) growing at three field experiments established in the mid-1990s in Zwierzyniec - the Experimental Forest near Kórnik belonging to the Institute of Dendrology of the Polish Academy of Sciences (described in publications as the Site 1), at the area of the experimental fields of the Institute of Dendrology in Kórnik (Site 2) and in the buffer zone of the Głogów copper smelter (KGHM Polska Miedź) in Żukowice (Site 3). The selected poplar genotypes represent well-growing and widely cultivated clones in Europe and the USA. In the past, i. A. the suitability of these genotypes was tested for filling areas degraded by industrial plants emitting air pollutants. The studies carried out at that time showed reduced DBH values of trees and differentiated resistance of individual genotypes in the polluted with heavy metals area (Rachwał et al. 1992; Rachwał - personal information). Plant material used to establish field experiments in the past as well as the poplar cuttings used in my experiments with seedlings were represented by the same poplar genotypes deriving from the collection of the Institute of Dendrology of the Polish Academy of Sciences in Kórnik.
Study sites were located on post-agricultural soils. Zwierzyniec and Kórnik represented areas relatively free of pollution (Fig. 1). Zwierzyniec was situated on the edge of a coniferous forest dominated by *Picea abies*. The site in Kórnik was been established between the plots of white poplars o the one side and the larch collection on the Rother side. Site 3, devoid of the vicinity of other trees, was located near the Odra River, in a part of the buffer zone of the copper smelter, which, due to the domination of winds from the plant's side, was most heavily

pressured by industrial pollution. The local soil significantly differed in its chemical characteristics compared to unpolluted sites in Zwierzyniec and Kórnik and has revealed an increased concentration of copper, lead, zinc and cadmium as well as carbon, nitrogen, phosphorus and potassium. On the other hand, there were no differences between soils of study sites In the concentration of N-NH3, calcium, and the carbon/nitrogen ratio (**Karliński et al. 2010; 2013; 2020; Karliński 2021a**).

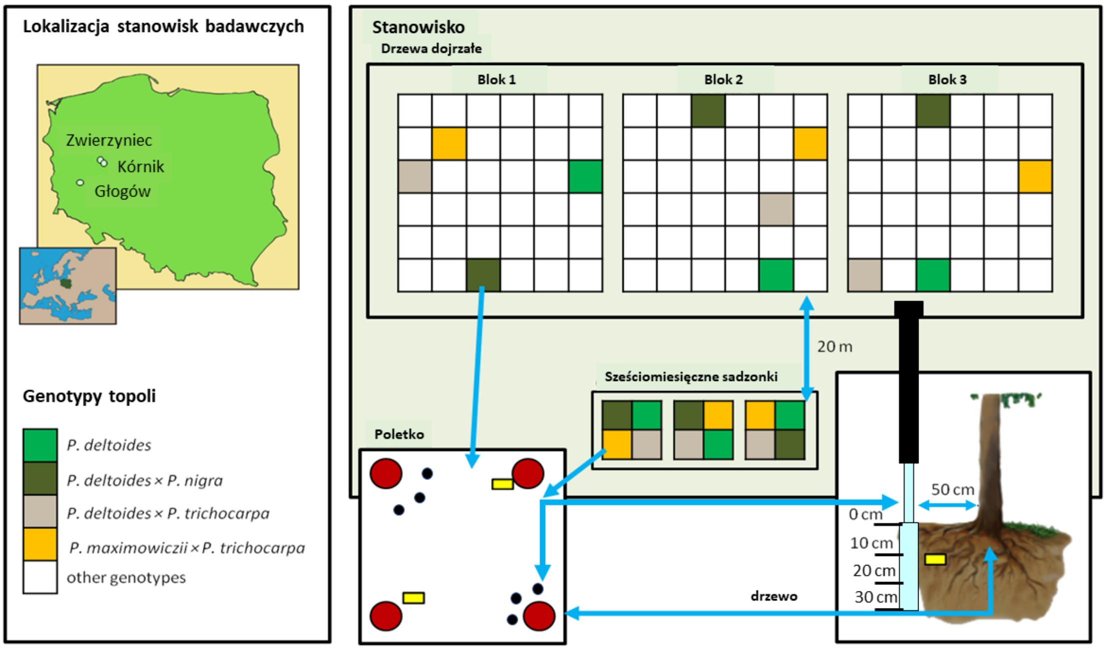

Fig. 1. The localization of study sites and schemes of the field experiments and soil, fine roots and fungal external mycelium sampling.

The presence of selected genotypes at three study sites, the repeated experimental setup in polluted and pollution-free areas, the availability of homogeneous plant material and the time distance from the start of the experiments, combined with the lack of previous studies of this type, created a unique opportunity for analyzing the influence of external soil factors and internal factors linked with trees genotype on the poplar microbiome In different soil strata.

In implementing the objectives of the study, the following elements were characterized:

- the abundance of fine root tips of selected poplar genotypes in the upper soil layer 0-30 cm
- the percentage of fine roots colonization by ectomycorrhizal and arbuscular fungi and fungal endophytes
- the characterisation of communities of ectomycorrhizal fungi
- the biomass of fungi in soil
- the biomass and contribution of arbuscular fungi, groups of soil fungi (including ectomycorrhizal fungi), Gram-positive and Gram-negative bacteria, actinomycetes and protozoa in the microbial community of the poplars rhizosphere
- the biomass of external mycelium of ectomycorrhizal fungi at mature tree sites and 6-month-old poplar seedlings

Karliński L, Rudawska M, Kieliszewska-Rokicka B, Leski T. 2010. Relationship between genotype and soil environment during colonization of poplar roots by mycorrhizal and endophytic fungi. Mycorrhiza 20, 315-324.

To determine whether and to what extent the poplar genotype and soil conditions influence the morphological diversity of fine roots of trees and their mycorrhizal colonization, I collected the samples from the upper soil layer of 0-30 cm, which were divided into subsamples 0-10 cm, 10-20 cm and 20-30 cm. The analysis of scanned root samples (WinRhizo 5.0 software) of four poplar genotypes (*P. deltoides*, *P. deltoides* × *P. nigra*, *P. deltoides* × *P. trichocarpa*, *P. maximowiczii* × *P. trichocarpa*)from Zwierzyniec, Kórnik and Głogów, revealed a significant impact of soil conditions and the soil depth on the abundance of fine root tips, which are a potential place for the formation of mycorrhizal symbiotic structures. Obtained results are in line with the general tendency pointing to local soil conditions (combining several features such as soil physicochemical properties, soil moisture, temperature, or the history of soil development and the impact of human use of soil) as the strongest factor affecting plants and communities of organisms associated with them (e.g. Leski et al. 2019; Rudawska et al. 2019). Soil pollution with heavy metals, especially in the case of copper and lead exceeding the allowable limits (Kloke 1980; Kabata-Pendias and Pendias 1993), resulted in lower biometric parameters of the roots of fine poplars in Głogów.
On the other hand, the stress conditions highlighted the role of the tree genotype, which generates different "root strategies" of individual poplars, which was not observed in unpolluted sites. In the case of most poplar genotypes, fine roots "escaped" into the deeper soil layers containing a lower concentration of heavy metals. Against this tendency, *P. deltoides* × *P. trichocarpa* stood out, for which the greatest number of fine roots was recorded in the top, most polluted soil layer.
The microscopic analysis of the roots stained with trypan blue (Kormanik and McGraw 1982; McGonigle et al. 1990) revealed the presence of arbuscular (AM), ectomycorrhizal (ECM) and fungal endophytes (FE) structures. The percentage of root fungal colonization positively correlated with the fungal biomass in soil (estimated based on the concentration of fungal-specific biomarker – ergosterol). Fungal colonization of poplar roots was mainly shaped by the local soil conditions (dominating factor), the soil depth and the genotype of the host trees. Soil pollution in Głogów had a particularly negative effect on root colonization by arbuscular fungi and, to a lesser extent, by ectomycorrhizal fungi. On the other hand, in the case of fungal endophytes, their contribution to the colonization of roots was significantly higher in Głogów than in the unpolluted sites. A similar tendency of increased fungal endophytes colonization of roots of other tree or herbaceous species in polluted areas was mentioned by Jumpponen and Trappe (1998), Routsalainen et al. (2007) and Likar (2011). It may suggest an important role played by this group of fungi in plant roots in the polluted with heavy metals areas. It is interesting that the roots of the hybrid *P. deltoides* × *P. trichocarpa*, mentioned earlier as the most tolerant to soil pollution, also revealed in the most polluted upper soil layer the highest colonization of fine roots by fungal endophytes. This may suggest the participation of this group of fungi in the processes of plant adaptation to the heavy metal pollution of soil. The obtained results also suggest a potential role of this group of fungi as an indicator of the presence of heavy metals in soils.

Arbuscular fungi were the dominant group colonizing fine poplar roots.
Contrary to the especially visible negative impact of soil pollution, soil moisture was the factor supporting arbuscular fungi in the colonization of tree roots. At unpolluted Zwierzyniec and polluted Głogów characterised by higher soil moisture, the ratio AM/ECM also presented higher values (9.8 and 8.6 respectively) than in more dryer Kórnik (AM/ECM=2.3). This result indicates the importance of soil moisture as a factor shaping the degree of colonization and the symbiotic relationships of plants with both arbuscular and ectomycorrhizal fungi (e.g. Lodge 1989; Querejeta et al. 2009).
The impact of host genotype on the colonization of the fine root by arbuscular, ectomycorrhizal fungi and fungal endophytes was observed at all study sites and this effect was modified by local soil conditions. The host genotype effect was also often linked with differences in soil depth. The obtained results confirm the niche hypothesis, according to which, in the upper soil layers, the root system is colonized to a large extent by ectomycorrhizal fungi, and in deeper layers by arbuscular fungi, which better tolerate the limited access of oxygen and nutrients (Neville et al. 2002). This is also indicated by the negative correlations observed between arbuscular and ectomycorrhizal fungi colonizing poplar roots in sites free of pollution. On the other hand, in the presence of heavy metals in soil, the results suggested the existence of competition between arbuscular fungi and fungal endophytes.
In summarizing, the presented research showed the importance of the analyzed factors determining the symbiotic relationships between mycorrhizal fungi and fungal root endophytes, and poplars. The genotype of trees marked its significant influence on the distribution of fine roots in the soil, the ability to establish symbiotic relationships with fungi and the tolerance of heavy metal pollution. However, the influence of the host genotype was significantly modified by environmental conditions influencing the development of the poplar fine roots and their colonization by fungi. Heavy metal pollution of soil significantly reduced the fungal biomass in soil and to a different extent, determined the contribution of individual groups of fungi in the colonization of the poplar roots.

Karliński L, Rudawska M, Leski T. 2013. The influence of host genotype and soil conditions on ectomycorrhizal community of poplar clones. European Journal of Soil Biology 58, 51-58.)

This study aimed to determine whether and to what extent the tree host genotype and soil conditions affect the composition and structure of ectomycorrhizal fungal communities. I analysed ectomycorrhizas associated with fine roots of mature poplars (four genotypes: *P. deltoides*, *P. deltoides* × *P. nigra*, *P. deltoides* × *P. trichocarpa* and *P. maximowiczii* × *P. trichocarpa*) in the upper soil layer 0-10 cm, 10-20 cm and 20-30 cm of three field experiments in Zwierzyniec, Kórnik and Głogów.
Based on the analysis of morphological features of mycorrhizas and their identification with molecular techniques (sequencing of the ITS rDNA region using ITS1F and ITS4 primers) I distinguished 27 taxa of ectomycorrhizal fungi. The analysis of the variance of ecological

coefficients describing the ectomycorrhizal communities pointed to the site conditions as a factor significantly affecting species richness, diversity (Shannon's coefficient) and the evenness of fungal species in these communities. The highest richness and species diversity of ectomycorrhizal communities was found in Zwierzyniec. The vicinity of the largest forest complex in Zwierzyniec, in comparison to other sites, may be an important source of fungal inoculum also for the studied poplars in this place. The lowest values of species richness and other ecological indices were noticed in polluted Głogów.

Soil depth was the second factor significantly shaping ectomycorrhizal communities of poplars. In all study sites along with the increase in soil depth, a decrease in the richness and biodiversity of mycorrhizal communities was noted. Also, the evenness of fungal species decreased in the deeper layers of the soil characterized by lower availability of oxygen and nutrients.

The overall comparison showed no significant effect of tree genotype on species richness and the structure of ectomycorrhizal communities associated with studied poplars. Such impact of genotype was noticed for instance in studies of slow- and fast-growing clones of *Picea abies* (Korkama et al. 2006). In the field experiments with poplars, all studied genotypes represented fast-growing trees. Observed higher growth parameters (DBH and tree height) for P. deltoides in comparison to the rest of the studied poplars did not reflect the differences in the richness and structure of ectomycorrhizal fungal communities.

In contrast, the analysis of individual study sites revealed significant differences in species composition of ectomycorrhizal communities associated with roots of *P. deltoides* × *P. trichocarpa* and *P. maximowiczii* × *P. trichocarpa* in Głogów. The first poplar genotype, as shown by previous studies (Karliński et al. 2010), was distinguished from the others by the tolerance of the root system to heavy metal pollution (the highest abundance of fine roots in the most contaminated topsoil). On the other hand, the latter genotype (*P. maximowiczii* × *P. trichocarpa*) was considered to be more sensitive to heavy metal pollution than other poplars (Rachwał et al. 1992). *P. maximowiczii* × *P. trichocarpa* also revealed the lowest ectomycorrhizal colonization of fine roots (Karliński et al. 2010).

The 27 fungal taxa (24 at Site 1, 22 at Site 2 and 18 at Site 3) that were identified in the present study were fewer than those found in previous studies on *P. tremula* (52) from a site contaminated with heavy metals (Krpata et al. 2008) or on other deciduous trees, but greater (11-14) than those found for other Salicaceae (Hrynkiewicz et al. 2008; Regvar et al. 2010). Probably relatively low species richness at the individual sites in the present study might be due to the location of the experimental sites in post-agricultural areas. Many studies from different parts of the globe have shown that long-term cultivation of soil with plant monocultures and the use of fertilizers decrease fungal diversity significantly (e.g. Merryweather 2001). In Głogów, in addition to the negative impact of heavy metal pollution, ectomycorrhizal communities could be limited by much higher concentrations of phosphorus in the soil than in other sites, which is a derivative of periodic floods related to the proximity of the Odra river (e.g. Baar et al. 2002). Analyses of ectomycorrhizal communities associated with roots of four poplar genotypes revealed the dominance of species belonging to Basidiomycota (88.8-98.2% of ECM root tips) at all study sites and only a low contribution of Ascomycota. The percentage of Ascomycota increased to 10.6% at the site in Głogów, indicating their greater tolerance to contamination with heavy metals. A similar tendency was

shown by Regvar et al. (2010) for *Salix caprea* on lead-contaminated soils. Most of the identified fungi belonged to the species found also in other representatives of the Salicaceae (eg Cripps 2004; Hrynkiewicz et al. 2008; Regvar et al. 2010; Bahram et al. 2011).
Soil chemical composition appeared to be a significant factor that modified the studied ectomycorrhizal communities. Ectomycorrhizas of *Cortinarius saniosus* were the most abundant in Głogów, where the soil, apart from the heavy metal pollution, was characterized by a low content of N-NO_3 and N-NH_4. In terms of 'exploration types' of ectomycorrhizas (as proposed by Agerer (2001)), *C. saniosus* corresponds to the medium-distance fringe exploration type and belongs to species sensitive to N deposition in soil (Hobbie and Agarer 2010; Lilleskov et al. 2011). Similarly, a high abundance of mycorrhizae of the medium-distance exploration type (represented by the taxon Atheliaceae) has been observed on *Pinus sylvestris* trees grown close to the site in Głogów (Rudawska et al. 2011). In contrast, *C. saniosus* was poorly represented at unpolluted sites in Zwierzyniec and Kórnik, characterized by a higher level of N-NO3 and N-NH4 in soil, where the most abundant representatives of the ectomycorrhizal community were different species of Tomentella (contact exploration type). These species are known for their positive response to N deposition in soil (Lilleskov et al. 2011; Hobbie and Agarer 2010). The similarity between two different tree species (Populus and Pinus) at similar sites in terms of the exploration type of ectomycorrhizal symbionts confirms the conjecture that the abundance of particular exploration types might be related to soil chemistry and nitrogen deposition in soil (Lilleskov et al. 2011; Hobbie and Agarer 2010; Rudawska et al. 2011).

Summing up, the results of this study indicate the dominant role of soil conditions in shaping the structure and species composition of ectomycorrhizal fungal communities associated with poplar fine roots. The genotype of trees plays a minor role in adapting to stressful conditions.

Karliński L., Ravnskov S., Rudawska M. 2020. Soil microbial biomass and community composition relates to poplar genotypes and environmental conditions. Forests 11, #262.

This study aimed to estimate the impact of poplar genotype on the biomass and community
composition of microorganisms in the rhizosphere of mature poplars in different soil conditions and at different soil depths.
Soil and root samples I collected from the upper soil layer 0-10 cm, 10-20 cm and 20-30 cm of four selected poplar genotypes (mature trees) growing in Zwierzyniec, Kórnik and Głogów. The microbiota of the poplar rhizosphere was characterised using techniques of extraction of whole cell fatty acids (WCFA) and their analysis with gas chromatography (Karliński et al. 2007). Based on signature fatty acids I estimated the biomass and contribution of Gram-positive and Gram-negative bacteria, actinomycetes, protozoa, arbuscular fungi and groups of soil fungi, including the composition of both ectomycorrhizal fungi (no specific markers for this group of fungi) and other saprotrophic and parasitic fungi. A total of 81 fatty acids have been identified from samples using TSBA41 database (Parsley 1996). The analysis of variance indicated the site as the main factor determining the biomass of Gram-positive and

Gram-negative bacteria, arbuscular fungi, a group of soil fungi and protozoa. As was observed in my previous studies, the highest values of biomass of most groups of microorganisms were found in Zwierzyniec and the lowest values were recorded in Głogów (**Karliński et al. 2010; 2013**). The negative effect of soil pollution in Głogów was particularly visible for protozoa. It suggests a potential role of this group of organisms as bioindicators of heavy metals in soil.

The second group, particularly sensitive to soil pollution were arbuscular fungi, which, compared to ectomycorrhizal fungi, in natural conditions usually present a higher tolerance of different stress factors, such as drought, high temperature, forest fire, periodic flooding and limited oxygen and nutrients access (Karliński 2021b and literature cited there). The lower concentration of the specific for arbuscular fungi fatty acid 16: 1ω5c in the samples from Głogów positively correlated with previously observed lower colonization of poplar roots by this group of fungi (Karliński et al. 2010). Similarly, a higher sensitivity of arbuscular fungi to heavy metal pollution of soil was observed in the case of pot experiments with poplars (Karliński – unpublished data).

In general, the negative effect of heavy metals was more pronounced in the case of fungi (both arbuscular and other groups) than in the case of bacteria. This result is convergent with results obtained near copper or zinc smelters, which showed a decrease in phospholipid fatty acids (PLFAs) as indicators of fungal biomass (Pennanen et al. 1996). Lower tolerance of fungi to heavy metal pollution than bacteria (Cu, Zn) was also confirmed in laboratory experiments (Rajapaksha et al. 2004).

Gram-negative bacteria were a predominant part of the microbiome irrespective of the site, confirming their dominance among the microorganisms in the rhizosphere and suggesting their tolerance to environmental pollution. Gram-negative bacteria are often indicated as the dominant group in soils contaminated with heavy metals, while Gram-positive bacteria are thought to be more sensitive than Gram-negative bacteria (O'Leary et al. 1988; Frostegård et al. 1993). However, examples of the opposite results, underlining the high tolerance of Gram-positive bacteria to heavy metal pollution, can be also found (Gupta et al. 2012). This is also the case in this study, where the contribution of Gram-positive bacteria at polluted Głogów was higher than at relatively clear Zwierzyniec and Kórnik. However, one must also be cognizant when making such broad comparisons between Gram-negative and Gram-positive bacteria of the dangers of overgeneralization across such diverse phylogenetic and functional groups of organisms.

Other factors significantly influencing the microbial communities in the rhizosphere of the three study sites were soil temperature (higher in Głogów) and soil pH (lower in Głogów). The higher temperature has a positive effect on the development of Gram-positive bacteria (Buyer et al. 2010), and it could have favoured a greater contribution of this group in the microbiota in Głogów. On the other hand, higher soil pH increasing the availability of organic matter could have stimulated the growth of the biomass of Gram-negative bacteria in Zwierzyniec and Kórnik (Frostegård and Bååth 1996; Pennanen et al. 2001).

The impact of soil conditions was also reflected in values of the ratio of fungi to bacteria (F:B), which was positively correlated with the C/N value of soils (Ananyeva et al. 2006). The F:B ratio of the sites in Zwierzyniec and Kórnik, ranging from 0.4 to 0.3, also reflected well the history of those plots that were agricultural areas in the past (Bailey et al. 2002).

The genotype of trees was also the factor significantly impacting the biomass of most of the studied groups of microbial organisms in the rhizosphere of poplars. The effect size of the tree genotype was different for the individual sites and microbial groups. The most pronounced impact of tree genotype was found for arbuscular fungi in Głogów reflecting, on the one hand, a differentiated tolerance of trees to stress conditions, and on the other hand, the close relationship of both symbiotes - poplars and arbuscular fungi.
The F:B ratio was previously shown as a suitable indicator of changes in the microbial community depending on the soil moisture gradient, and changes in soil management or soil pollution (Bailey et al. 2002; Zhang et al. 2016). Obtained results also revealed F:B ratio as a good indicator of the poplar genotype effect both in an overall comparison of genotypes and in the relationship among genotypes at individual sites. At each site and at most depths, *P. deltoides* showed higher values of the F:B ratio than did the other poplar genotypes.
This may be related to the ability of plants to structure the biomass and microbial community Schweitzer et al. 2008). The higher F:B values found in P. deltoides (especially at polluted Głogów), may suggest, that in comparison to the other studied poplar genotypes, P. deltoides has a greater ability to form the symbiotic interactions with fungi. This trait is confirmed by a greater number of ectomycorrhizal species found on the roots of this poplar, especially under polluted conditions(**Karliński et al. 2013**).
The interaction of plants and fungi may have a positive effect on the higher growth parameters (tree height and DBH) of P. deltoides compared to other poplars (**Karliński et al. 2013**). On the other hand, the larger size of the aboveground part of a tree (implicitly a larger photosynthetic apparatus), may result in higher production of carbon compounds, directed through the roots to the soil, and the formation of this an attractive offer for a wider group of soil fungi as their consumers. Fungi are known to be a group of organisms that use organic substrates more efficiently in the production of biomass than bacteria (Holland et al. 1987; Joergensen et al. 2008). The higher biomass of fungi in the rhizosphere of *P. deltoides* positively correlates with the higher production of biomass of external mycelium in the soil than in other poplars (**Karliński 2021a**).
Also, the ratio of the biomass of arbuscular fungi and soil fungi (consisting of ectomycorrhizal fungi, saprotrophs, pathogens) (AM:SF) was found to be significantly impacted by tree genotype. However, both groups of fungi (AM and SF) were influenced by genotype and local site conditions to varying degrees. The role of both groups of fungi in soil nutrient cycling, including different soil depths and the character of their interactions with the tree roots, are not equivalent (Holste et al. 2017).
The AMF:SF biomass ratio showed a more local variation between genotypes, and it was difficult to determine a consistent trend for all genotypes at all study sites. The relationship between AMF and SF biomass in soils corresponds quite well to the results of poplar root colonization by arbuscular and ectomycorrhizal fungi (**Karliński et al. 2010**). Despite the lack of a specific marker for ectomycorrhizal fungi in the soil, it suggested a dominant contribution of ectomycorrhizal fungi to the biomass of a group of soil fungi.
The ratio of Gram-positive bacteria to Gram-negative bacteria is an example of the lack of the genotype impact on the biomass of both groups of microorganisms, which is shaped mainly by the site and soil depth.

The decrease of the microorganisms' biomass with soil depth is a common feature observed for various types of soil and plant communities (Fierer et al. 2003; Ostonen et al. 2005). However, as our research has shown, trends in changes in the contribution of various groups of organisms may differ, which is determined both by environmental factors and the tree genotype. For example, the contribution of Gram-positive bacteria in most cases (the exception: *P. deltoides* in Głogów) increased with soil depth. Their high contribution in the deeper soil layers may reflect the tolerance of Gram-positive bacteria to the limited availability of carbon and oxygen (Song et al. 2008; Hobley and Wilson 2016). On the other hand, the increase in the availability of carbon in the topsoil favoured Gram-negative bacteria and fungi (Fierer et al. 2003). This tendency was disturbed in the case of Głogów, where the highest concentration of heavy metals deposited mainly at the upper soil layers, determined the migration of fungi and bacteria to the deepest soil layers. The increase of the contribution of arbuscular fungi in the rhizospheric microbiota of poplars at the deepest soil layers (especially in Kórnik and Głogów), reflected a similar picture presented by the results of previous studies of the poplar fine root colonization by this group of fungi (**Karliński et al. 2010**).

Contrary to arbuscular fungi, the presence of protozoa was strongly associated with the topsoil and their biomass significantly decreased with soil depth. It is linked with the availability of organic carbon in soil and with microbial biomass in general, which influences the abundance of higher trophic level protists (Henkes et al. 2018).

The soil depth was the main factor that negatively influenced the biomass of actinomycetes at study sites. It differed from the findings of Fritze et al. (2000) and Fierer et al. 2003, who noted that there was a higher actinobacteria abundance in deeper soil layers than in the upper soil layers. In our study, this was presumably the result of a decrease in available nitrogen compounds at deeper soil layers rather than soil pH, as suggested by Fritze et al. (2000).

In summarizing, the presented study revealed a significant influence of soil conditions (as a dominant factor), soil depth, genotype of the tree and the interaction of these factors on the biomass and the structure of the microbial community in the rhizosphere of poplars. A significant impact of tree genotype on soil microorganism communities was particularly evident in Głogów, perhaps due to the increased environmental pressure caused by soil pollution. The poplar genotype determined the contribution of microorganisms, especially fungi and bacteria (F:B ratio) at individual sites and their distribution in the soil profile. Fungi seem to be more related to poplar genotype, while the bacteria depend on the local site conditions to a greater extent. Also, the biomass ratio of arbuscular fungi and soil fungi was found to be significantly influenced by the poplar genotype, contributing to the structure of the microbiome, despite the different characteristics of interactions with host trees. Obtained results revealed that the diversity of rhizospheric microbial communities according to the soil depth was significantly affected by both soil conditions and the genotype of the trees. The soil microbiome showed a relatively stable proportion of different groups of microorganisms at three study sites and confirm the high adaptability of poplars to different soil conditions.

Karliński L. 2021. Biomass of external mycelium of mycorrhizal fungi associated with poplars – the impact of tree genotype, tree age and soil environment. Applied Soil Ecology 160, #103847.)

This work aimed to fill the gap in knowledge regarding the biomass of fungal external mycelium of ectomycorrhizal fungi associated with the roots of poplars, growing in different soil conditions.

The first goal was to estimate the impact of the poplar genotype on the biomass of external mycelium of ectomycorrhizal fungi, and the second goal was to estimate the impact of tree age and environmental soil conditions on the biomass of external mycelium of these fast-growing trees.

The studies were carried out at three previously described field experiments in Zwierzyniec, Kórnik and Głogów, and with the same four poplar genotypes - *P. deltoides*, *P. deltoides* × *P. nigra*, *P. deltoides* × *P. trichocarpa*, *P. maximowiczii* × *P. trichocarpa*). Additionally, in the vicinity of the mature trees, new field experiments were established with poplar seedlings of these same four genotypes obtained from the collection of poplars of the Institute of Dendrology PAS. The cuttings were rooted in pots containing soil from three sites and after a month they were planted in the field in a system of three blocks containing plots (4 plants) of four poplar genotypes (Fig. 1). Samples of the external mycelium of ectomycorrhizal fungi were collected using the in-growth mesh bags method (Wallander et al. 2001; Karliński et al. 2015). Mesh bags were filled with quartz sand being theoretically too poor environment, which decrease the in-growth of saprotrophic fungi (Wallander et al. 2001). The mesh bags were placed within the plots of four genotypes of mature trees and seedlings at a depth of 10 cm for five months, which seems to be the optimal time of in-growth for mycelium, established based on literature and own experience (Karliński et al. 2015). The biomass of external mycelium was estimated using the fungal-specific biomarker – ergosterol, which concentration was measured with the high-performance liquid chromatography (HPLC) techniques taking into account the biomass conversion factors proposed by Montgomery et al. (2000).

The external mycelium of ectomycorrhizal fungi was detected in all quartz-sand filled mesh bags placed in the vicinity of mature trees and seedlings. The analysis of the control bags did not reveal the presence of ergosterol or only its very low concentration was detected, which was probably a derivative of saprotrophic fungi, as the results of studies by Wallander et al. (2001) suggest.

The upper biomass values of external mycelium of ectomycorrhizal fungi associated with mature poplars and seedlings were similar. The external mycelium biomass found in both age groups of poplars was higher than values noticed for mixed *Betula pendula*, *Picea abies* and *Pinus sylvestris* forests reported from Finland (Kalliokoski et al., 2010) and were much higher than data reported by Bakker et al. (2015) for *Fagus sylvatica*, *Quercus petraea* and *Pinus pinaster* in France. However, in the latter study, mesh bags were incubated in the soil for only one to three months (Bakker et al. 2015). Our data are within the range of values characteristic for Scandinavian coniferous trees (*Picea abies*, *Pinus sylvestris*) (Ekblad et al. 2013) and *Pinus pinaster* in France after 12 months of mycelium in-growth (Bakker et al. 2015). It is difficult to deduce any trends of geographical or tree-host related variation of

external mycelium biomass because available literaturę data for the temperate zone and deciduous trees are very limited.
The obtained data were in line with the series of previous results, indicating the important role of both the genotype of trees and the soil environment (**Karliński et al. 2010; 2013; 2020**), as well as the age of tree hosts.
The impact of the tree genotype on the biomass of the external mycelium was much stronger for young seedlings than for mature trees. This is consistent with the tendency of the gradual disappearance of tree specificity over time, also observed for many other plant features, which may be the result of the adaptation of trees to local environmental conditions (Grams and Anderssen 2007; Gratani 2014). The observed impact of poplar genotype on the biomass of external mycelium underlines the close relationship between tree host and associated mycorrhizal fungi. A similar effect was previously found for the contribution of fungi in the rhizosphere microbiome of poplars. Fungi present much higher genotype dependence than other microbial groups in the rhizosphere (e.g. gram-positive and gram-negative bacteria) (**Karlinski et al. 2020**). Among the examined poplar genotypes of mature trees and seedlings, *P. deltoides* tended to present a relatively high biomass of external mycelium, compared to other poplars. This result corresponds well with the higher fungal biomass previously found in the soil rhizosphere of this poplar genotype (**Karliński et al. 2020**). Similarly, *P. deltoides* was also characterised by significantly higher biometric parameters for the aboveground part of the trees (expressed as diameter and tree height) (**Karliński et al. 2013**). This may suggest a positive relationship between the size of trees and the production of external mycelium biomass in soil. The higher aboveground biometric parameters of *P. deltoides* may provide better access to light and as a consequence, more efficient production of sugars by photosynthesis. Nearly 30% of the carbon produced in the leaves can be transferred to the fungal partners, one of the main routes of carbon movement from trees to soils (Nehls et al. 2010; Smith and Read 2008). Finally, the higher production of sugars may stimulate more efficient development of external mycelium (Wright et al. 2000; Szuba et al. 2019) directly or by changes in mycorrhizal communities (Hoeksema and Classen 2012; Ekblad et al. 2013; Lamit et al. 2016).
As in our earlier studies, also here the highest values of external mycelium biomass were noticed in Zwierzyniec and the lowest in Głogów. In the case of mature trees, the lack of significant differences in biomass of external mycelium may be the result of a previously mentioned process of adaptation of trees to local environmental conditions. It could be also the reason of the gradual reduction of heavy metal emissions to the soil by the copper smelter in Głogów. In the case of young poplars, the water deficit was a more visible factor than contamination with heavy metals, which may indicate the importance of this factor as a key factor in the formation of external mycelium.
The overall comparison of mature trees and seedlings showed a significant influence of plant age on the production of external mycelium biomass of ectomycorrhizal fungi. However,
in most cases, the observed differences were rather small. The relatively high biomass of external mycelium noticed for six-month-old poplar seedlings differed from the picture observed by Wallander et al. (2010) for Scandinavian *Picea abies*. These authors observed a clear increase in the production of external mycelium biomass with the age of trees up to 10-20 years and a gradual decrease of mycelial biomass in the older age classes of *Picea abies*.

The similarity of external mycelium biomass production beneath deciduous mature poplar trees and seedlings in contrast to coniferous Norway spruce may result from different strategies for maintaining adequate mineral nutrition during the vegetation season, as shown for Betula pendula and Picea abies by Kalliokoski et al. (2010). Establishing a network of external mycelium in the case of young plants is a much more energy-consuming process than in mature stands (Wallander et al. 2010). Willows and poplars are pioneer trees, establishing symbiotic associations not only with ectomycorrhizal fungi but also, especially at an early age, with arbuscular fungi, which are less demanding (Smith and Read 2008). Thus the dependence on carbon as a factor determining external mycelium biomass production may be in the early growth stages of these trees, lower than in conifers.

The relatively high production of external mycelium biomass in young tree stands may be explained by the strategy of nutrient investment, primarily directed to the development of mycelium networks and the exploration of the new environment. In the case of mature stands, where the fungal network is already well developed, more energy may be provided for the development of fruiting bodies at the expense of the production of external mycelium (Ekblad et al. 2016).

Both carbon and nitrogen are important factors for the production of external mycelium in soil and fungal communities (Cairney 2012; Hagenbo et al. 2018). The positive correlations of the external mycelium biomass with the content of carbon and nitrogen in the soil, which I observed in young seedlings, emphasize the importance of the availability of these nutrients for the formation of external mycelium biomass in the early period of tree development. However, for mature poplars, such a relationship was not noted.

I also found a negative correlation between the biomass of the external mycelium formed under young poplar seedlings and the concentration of $N\text{-}NH_3$ in the soil. A similar negative relationship was observed by Nilsson and Wallander (2003) in spruce stands fertilized with ammonium sulphate, which led to a reduction of the fungal contribution to the soil microbiome and it favoured the growth of nitrogen oxidizing bacteria (Tatsumi et al. 2020).

In the case of the sites I studied, their agricultural history and specificity of soils including heavy metal pollution at Głogów could have an impact on soil nitrogen transformations and the production of the biomass of external mycelium.

Summing up the obtained results indicated comparable values of external mycelium biomass for mature trees and six-month-old seedlings. The biomass of the external mycelium was significantly impacted by the poplar genotype. Soil conditions had a greater effect on the external mycelium biomass of seedlings than on mature trees, which did not reveal a significant influence of site. For seedlings, soil moisture, carbon and nitrogen concentrations supported the external mycelium biomass. Soil moisture more than heavy metal pollution shaped the fungal biomass of seedlings.

Karliński L. 2021. The arbuscular mycorrhizal symbiosis of trees: Structure, function and regulating factors. In: Shrivastava N., Mahajan S., Varma A. (eds.) Symbiotic Soil Microorganisms. Biology and Applications. Springer. 117-128.

This review aimed to present the most important facts about arbuscular fungi and the mycorrhizal symbiosis they co-create with woody plants. Arbuscular mycorrhiza is evolutionarily the oldest and most common type of symbiosis of plants (over 200,000 plant species) and fungi belonging to the phylum Glomeromycota (Lee et al. 2013). Apart from the natural functions of arbuscular fungi, this type of symbiosis plays several important roles in the human economy. Most crop plants and fruit trees reveal symbiotic associations with arbuscular fungi. This also applies to many ornamental plants and plants used in industry. Arbuscular fungi dominate in relatively rich, fertile and phosphorus-limited soils. The tropical zone is the area of the most common occurrence of arbuscular fungi and their greatest species diversity. On the other hand, the communities of arbuscular fungi reveal high heterogeneity and plant genotype dependence (Chen et al. 2018; Soudzilovskaia et al. 2019; Tedersoo and Bahram 2019). Due to a wide range of tolerance of often very extreme environmental conditions, arbuscular fungi are also observed in dry and semi-arid areas as well as in wetlands. Despite the prevalence of arbuscular mycorrhizal symbiosis, knowledge regarding this group of fungi and their communities is still full of gaps and question marks. In this review, based on current knowledge I briefly discussed in the following subchapters the main types of mycorrhizal symbiosis (arbuscular mycorrhiza, ectomycorrhiza, ericoid mycorrhiza, orchid mycorrhiza, monotropoid mycorrhiza and arbutoid mycorrhiza) and their history of evolution. I presented the taxonomic division of fungi belonging to the phylum Glomeromycota and distinguished here the four orders Archeosporales, Diversiporales, Glomerales and Paraglomerales distinguished here (Błaszkowski 2012). Next, I described specific structures formed by arbuscular fungi in the roots and the types of root colonization. In the further part of the review, I discussed the distribution of arbuscular fungi at the planete and pointed out some examples of the species of trees and shrubs establishing symbiotic relationships with arbuscular fungi, as well as trees characterised by dual mycorrhizal symbiosis with arbuscular and ectomycorrhizal fungi. Then, based on the literature data as well as on my observations of poplars, I discussed the main environmental factors shaping the mycorrhizal relationships of arbuscular fungi and trees and the differences in tolerance of arbuscular and ectomycorrhizal fungi to different factors.

5. Presentation of significant scientific or artistic activity carried out at more than one university, scientific or cultural institution, especially at foreign institutions

Scientific activity before obtaining a doctoral degree

In 2001, I graduated from the Faculty of Biology at the University of Adam Mickiewicz in Poznań. Master's thesis entitled "Diversity of Scots pine (*Pinus sylvestris* L.) from the area of Bory Tucholskie, examined based on morphological features of needles" I prepared under the supervision of prof. Lech Urbaniak at the Department of Genetics. Apart from the studies on the variability of the morphological features of the needles of the Scots pine populations from the dry and peat bog areas of the Tuchola Landscape Park, I also participated in studies of the Scots pine populations from their relict stands in the Tatras and Pieniny Mountains. As a member and later chairman of the Genetics Section of the Scientific Group of Naturalists at the Faculty of Biology of the Adam Mickiewicz University, I also participated in studies on the diversity of the Scots pine populations in the Wielkopolska National Park, using both morphological isoenzymatic techniques. This period resulted in participation in several national scientific conferences and co-authorship of the five articles published in indexed journals and post-conference proceedings (Urbaniak et al. 2000a, b; Urbaniak and Karliński 2001; Urbaniak et al. 2001; Urbaniak et al. 2003).

After graduation, I continued my research career as a PhD student at the Institute of Dendrology of the Polish Academy of Sciences, in the Laboratory of Mycorrhizal Research in Kórnik under the supervision of prof. Barbara Kieliszewska-Rokicka. My studies focused on the communities of ectomycorrhizal fungi and soil microorganisms associated with Norway spruce growing in different habitats and various degrees of anthropopressure and heavy metals pollution. These studies showed significant quantitative and qualitative differentiation of ectomycorrhizal fungal communities and other groups of soil microorganisms present in mature spruce forests and their strong dependence on environmental conditions. During my doctoral studies, I had the opportunity to use several research techniques, including new ones, not previously used both in our Institute and on a national scale, which I have been successfully using to this day.

During my doctorate, I received a Danish government scholarship for a six-month internship at the Institute of Agricultural Sciences - Research Center Flakkebjerg in Denmark. The stay at the Research Center Flakkebjerg was the beginning of long-term cooperation with dr John Larsen and assoc prof. Sabine Ravnskov, which is continued to this day. In Denmark, I carried out a project entitled "The effect of inoculation with ectomycorrhizal fungi and mycorrhizal helper bacteria on the response of Norway spruce seedlings to lead" (Karliński et al. 2003). During my internship, I had an opportunity to learn and use in my studies the techniques of fatty acid ester extraction and their analysis with gas chromatography. I also significantly expanded my knowledge of the cultivation and analysis of bacterial strains (MHB). In addition to the basic research topic, the achievement that I gained during the internship was the testing the possibility of effective use of fatty acid techniques in the studies of ectomycorrhizae containing both fungal and plant structures and the reveal of their specific profiles.

The next year I visited Flakkebjerg again. During this stay, I was analysing the impact of time on fatty acid profiles of selected ectomycorrhizal fungi cultivated in in-vitro cultures and again demonstrated the usefulness of these techniques in the analysis of ectomycorrhizal fungi. The obtained results were included in the doctoral dissertation and were published in international indexed journals (Karliński et al. 2003; Karliński et al. 2007), and presented at international conferences in Italy, France and Poland. In Denmark, I also participated in the studies of the effect of co-inoculation of tomato cultivars with strains of the arbuscular fungus *Glomus intraradices* (now - *Rhizophagus irregularis*) and the biocontrol agent fungus

(*Clonostachys rosea*) on the growth parameters of plants and the community of soil microorganisms. The results showing the positive effect of both species of fungi have been presented in the repeatedly cited publication by Ravnskov et al. 2006.

In 2007, I defended my doctoral thesis entitled "Ectomycorrhizal communities of Norway spruce and soil microorganisms in mature forest stands" and obtained a PhD in biological sciences. The doctoral thesis was awarded by the Council of the Institute of Dendrology of the Polish Academy of Sciences in Kórnik.

Scientific activity after obtaining a doctoral degree

After obtaining the PhD degree in biological sciences, my research interests focused on the analysis of the influence of the tree genotype and soil environment diversity on the mycorrhizal fungal community associated with poplars. The opportunity to initiate this research was the participation in the European project EVOLTREE (Evolution of Trees) and in the activities of the JERA 3 group, which resulted in publishing a review paper (Gugerli et al. 2013) and numerous conference presentations (Attachment 4).

The subjects of these studies were the communities of ectomycorrhizal fungi and insects as groups associated with trees represented by local black poplar (*Populus nigra* L.) genotypes and poplar hybrids originating from international exchange. The extension of the duration of two field experiments established during the EVOLTREE project in the Institute of Dendrology PAS, made it possible to take into account additional factors – the survival of individual poplar genotypes and the production of biomass, which after ten years are currently analysing. Participation in the EVOLTREE project allowed me to deepen my experience related to international cooperation with various research groups and the specificity of large European projects, as well as expand my knowledge in the field of statistics and experiment planning (Attachment No 5).

The research project, which I obtained from the Ministry of Science and Higher Education, allowed me to broaden my interests in the analysis of poplar genotype and environmental impact on both ectomycorrhizal and arbuscular fungal communities, and other soil microorganisms settled in the upper soil layer 0-30 cm of polluted and unpolluted areas. My project based on selected poplar genotypes from the collection of the Institute of Dendrology PAS and unique field experiments from the first half of the 90s became the basis of the presented achievement.

Poplars (here *Populus nigra*) were also the object of lately realised studies in cooperation with the Department of Environmental Biology of the Kazimierz Wielki University in Bydgoszcz.

Analyzes of soil microbiota in the natural habitats of the black poplar, to a different extent subjected to periodic river floods, showed a significant impact of soil hydration and the concentration of carbon, nitrogen and phosphorus on the activity of soil microorganisms (Frymark-Szymkowiak and Karliński 2022).

In addition to studies on the influence of plant genotype and environmental conditions on soil microbiota, I also participated in studies of the influence of various genotypes of the ectomycorrhizal fungus *Paxillus involutus* on the ability to establish symbiosis with poplars (*Populus* x canescens). The analyses were carried out in in-vitro cultures. The obtained results

showed differences in the ability to establish symbiotic relationships by fast- and slow-growing strains of P. involutus with poplar and their differentiated impact on plant growth parameters and changes in the proteome of poplar leaves (Szuba et al. 2017; Szuba et al. 2019).
Research on the influence of the genotype of the fungus Rhizoctonia solani (pathogenic and non-pathogenic strain) on the communities of associated bacteria in different soil conditions was the main topic of my postdoctoral fellowship under the Danish Government Scholarship, which I realized at the Faculty of Agricultural Sciences of the University of Aarhus (Research Center Flakkebjerg). By implementing the project, I showed significant qualitative and quantitative differences in bacterial communities accompanying the strains of this dangerous fungal parasite of many plant species (manuscript in preparation). In addition, several dozen isolated and identified bacterial strains may constitute a starting point for further studies on their role in fungus-plant interactions.
Besides long term cooperation with Denmark and mentioned participation in the European project EVOTREE, I was also involved in the work of international teams in COST projects - BioLink (FP1305 - Linking belowground biodiversity and ecosystem function in European forests) and SENSFOR (ES1203 - Enhancing the resilience capacity of SENSitive mountain FORest ecosystems under environmental change). The first project resulted in a short-term internship organized at our Laboratory of Symbiotic Associations (previously Laboratory of Mycorrhizal Research) in the Institute of Dendrology PAS in Kórnik, during which we hosted dr. Jovana Devetaković from the Faculty of Forestry, University of Belgrade. During this short-term scientific visit, we analyzed the mycorrhizal status of *Ulmus laevis* from different sites in Serbia (Devetaković et al. 2015). In the case of the second project, I participated in works related to the analysis of factors affecting the treeline dynamics of mountain forests, which provides numerous ecosystem services. This activity has been finalized in a form of a report and publication in the journal „Soil Research" (Broll et al. 2016; Moscatelli et al. 2017).

During the years from my dissertation, I participated in a number of projects and research tasks carried out at the Laboratory of Symbiotic Associations, and related to the forest management, the effect of fertilization (different fertilizers and their doses) on pine seedlings and their mycorrhizal symbionts in forest nurseries, or the comparison of ectomycorrhizal communities of the popular deciduous tree species (*Betula pendula*, *Carpinus betulus*, *Tilia cordata*, *Faus sylvatica*) cultivated in forest nurseries (Rudawska and in. 2019; Pietras et al. 2013).

During the long-term cooperation of our Laboratory with the Botanical Garden of the Vilnius University, I participated in analyses of the impact of soil enrichment with pine litter on *Pinus sylvestris* seedlings grown in forest nurseries. Our results showed a positive effect of this treatment on the improvement of the quality of the root systems of pine seedlings, presenting well developed symbiotic associations with ectomycorrhizal fungi (especially group of the suilloid mycorrhizas). We also noticed the enhanced survival of outplanted pine seedlings in unfavourable ecological conditions (Rudawska et al. 2017).

I also participated in a project related to forest management and its impact on the fungal community. The results obtained during the several visits to managed and unmanaged study sites allowed for the conclusion that both managed and unmanaged forests contribute to the maintenance of the diversity of fungi from various trophic groups. Forest management generally supported the presence of a larger pool of fungal species in European mixed forests (*Querco roboris-Pinetum*). Each of the analyzed forms of management also determines the presence of a specific group of fungal species (Leski et al. 2019).

I was also a participant in a project financed by the General Directorate of State Forests, the topic of which was the biodiversity of fungi in the Białowieża National Park and beyond its borders, including declining stands of *Picea abies*. These studies provided a lot of interesting information on the communities of ectomycorrhizal fungi, especially a group of tomentelloid fungi.

Getting to know the biodiversity of fungi of various taxonomic and trophic groups was also the aim of the workshops of the Polish Mycological Society in which I participated many times. The workshops are organized in national parks and forest reserves with the poorly recognized fungal community. It allowed to significantly expand the knowledge about the funga of the Biebrzański National Park, Stołowe Mountains National Park, Narwiański National Park, Borecka Forest, Polanów Forest District (Kujawa et al. 2012; Kujawa et al. 2016).

The biodiversity of fungi in the pine and beech forests of the southern and south-eastern coast of the Baltic Sea is also the topic of the projects in which I currently participate in cooperation with the Botanical Garden of the Vilnius University and the University of Szczecin. The analyzes carried out so far have allowed us to better understand the diversity of fungal communities and their seasonal variability in the coastal beech forests. In the case of Scots pine, we noted significant differences in the abundance and species composition of mycorrhizal fungi linked with the vertical distribution of pine forests at coastal dunes.

In addition to studies of forestal communities of fungi, my scientific interests also focused on transformed and mosaic in their character urban conditions, which often favour the occurrence of tree species alien to the local flora. One of these tree species is *Aesculus hippocastanum*, which is a very popular and common tree in urban landscapes. However, the knowledge of their root morphology and symbiotic relationships with mycorrhizal fungi was very poor. Our studies conducted in the urban conditions of Poznań and in the agricultural landscape of Trzebaw completed this gap in the literature (Karliński et al. 2014). We revealed significant plasticity of this species, both in terms of its root system and symbiotic associations with arbuscular fungi and a good adaptation of *Aesculus hippocastanum* to both urban and rural conditions.

I also participated in the research of other representatives of species alien to the Polish flora, such as hickory growing in the Kórnik Arboretum (*Carya laciniosa* (Michx.) Don and *Carya cordiformis* (Wangenh. Koch)), also poorly known for their relationship with mycorrhizal fungi. The analysis of their roots showed, as in the case of poplars, the presence of dual colonization of fine roots by ectomycorrhizal and arbuscular fungi (Rudawska et al. 2018). In the case of the five-leaf hickory (*Carya ovata* (Mill.) Koch) growing in forest conditions, the presence of only ectomycorrhizal structures was detected (Wilgan et al. 2020). Currently, I also participate in studies of the arbuscular mycorrhizal symbiosis of *Ulmus laevis* growing in urban conditions and areas under strong anthropogenic pressure.

In addition to the research issues mentioned here, I also participated in experimental works aimed at adapting analytical methods to the specificity of our laboratory's research and using them in our further research, or optimization of already used, e.g. analysis of fatty acids profiles of mycorrhizal sporocarps, in-vitro cultures of mycorrhizal fungi and ectomycorrhizas (Karliński et al. 2007); ergosterol extraction using the modified MAE method (Karliński et al. 2010; 2015; 2021b), co-inoculation of *Populus* x canescens in vitro cultures with ectomycorrhizal fungi (*Paxillus involutus* and *Hebeloma crustuliniforme*) and arbuscular fungus *Rhizophagus irregularis* (strain – BEG 87) and the acclimatization of obtained in vitro plats in soil under the influence of heavy metal contamination (Bojarczuk et al. 2015) or methods of DNA isolation of ectomycorrhizal fungi (Janowski et al. 2019).

Summarising, I am the author and co-author of 24 scientific articles indexed by Journal Citation Reports and 9 non-indexed papers prepared in cooperation with various Polish research teams and from abroad (Attachment No 5).
My total impact factor for the year of publication is: 80.614.
The total number of MEiN points (for the year of publication) is 1477. I am also the author of 8 popular scientific articles.
I am the author or co-author of 17 oral presentations and 23 posters presented at international conferences and 33 oral presentations and 9 posters presented during the national conferences
During my PhD studies and my employment in the Institute of Dendrology PAS, I also improved my skills by participating in two long-term foreign internships and other 1-2 weeks and shorter workshops and courses in Poland and abroad. (Attachment No 5).
I also prepared 27 (often multi-stage) reviews of articles for publication in the international scientific journals (Attachment No 5)
Two times I participated in the commission reviewing the research projects of young scientists applying for funding by the Institute of Dendrology of the Polish Academy of Sciences.

6. Presentation of teaching and organizational achievements as well as achievements in popularization of science or art.

During my master's studies, I participated in meetings with younger students, presenting research issues carried out at the Department of Genetics at the Faculty of Biology of the Adam Mickiewicz University. The purpose of the meetings was to help in choosing the place and the subject of the master's thesis and encouragement to develop their research interests in the Department of Genetics.

As a member and later chairman of the Genetics Section of the Scientific Group of Naturalists at the Faculty of Biology of the Adam Mickiewicz University, apart from research, I participated in meetings and took other actions popularizing the activity in our section.
In the course of my master's studies, I additionally completed a pedagogical block authorizing me to teach nature and biology in primary and secondary schools, where I also did internships.

During my doctoral studies, I taught exercises in plant physiology and mycology at the Kazimierz Wielki University in Bydgoszcz. I also participated in mentoring students from Bydgoszcz, who were completing some of their bachelor’s or master's theses in the Laboratory of Symbiotic Associations (formerly Laboratory of Mycorrhizal Research), introducing them to the techniques of ectomycorrhizae analysis, preparation of the root intersection and microscope slides, photographic documentation, as well as scanning of root samples to determine their biometric parameters, preparing mesh bags for collecting external mycelium of mycorrhizal fungi in the soil, preparing in vitro cultures of ectomycorrhizal fungi, compiling data using various statistical techniques, etc. In the case of some of the research techniques mentioned, teaching them has also been the goal of several visits by foreign researchers from Denmark and Lithuania.

At our Laboratory, I conducted several-day courses in the techniques of staining and assessing the colonization of fine roots of different plant species by arbuscular fungi for researchers and students from Poland (Adam Mickiewicz University, Poznań University of Life Sciences, Institute of Dendrology of the Polish Academy of Sciences) and from abroad (Serbia). I also presented the techniques of ergosterol extraction (a biomarker of fungal biomass) and evaluation of its content in samples using high-performance liquid chromatography (HPLC) to the employees of the Kazimierz Wielki University in Bydgoszcz and the Institute of Dendrology of the Polish Academy of Sciences.

During my postdoctoral internship at the Aarhus University (Faculty of Agriculture Research Center Flakkebjerg, Denmark) in collaboration with the Institute for Ecosystem Research and Sustainable Development of the National Autonomous University of Mexico (UNAM), I provided scientific supervision to a student from this university during her analysis of soil microbial communities, introducing her to techniques of fatty acid extraction, separation and identification using gas chromatography (GC) and subsequent analysis of the resulting data.

I was also a co-supervisor of two bachelor's theses prepared in the Institute of Dendrology PAS, the results of which were published in a highly impacted scientific journal (Karliński et al. 2014).

I also participated in a series of lectures for PhD students of the Poznan Doctoral School of Institutes of the Polish Academy of Sciences, giving a lecture on the subject of „Ecology of woody plants”: "The arbuscular mycorrhizal symbiosis of trees. Structure, function and regulating factors".

During my PhD studies and later, I had the opportunity to educate and popularize the research topics of our Laboratory during visits of researchers and students from Poland and other countries (e.g. Slovenia, Portugal, Russian Federation) as well as during the visits of school excursions from Kórnik, Poznań, or Trzemeszno. Also during the scientific conferences organized by the Institute of Dendrology PAS I participated in presentations of our scientific activities to the conference guests.

In addition to scientific papers directed mainly to professionals, I also publish articles popularising the science addressed to foresters and naturalists (Karliński 2019; 2020; 2021c; Leski et al. 2019) as well as to local recipients (Karliński 2021d; 2021e; 2022; Karliński and Karlińska 2021).

A form of popularization of knowledge on different species of fungi present in Polish forests was also my participation in annual field workshops of the Polish Mycological Society, held in areas of poorly known fungal communities. These workshops resulted in lists of fungal species of various systematic and trophic groups, identified during our stay and in subsequent laboratory analyses. In this way, both professionals, hobbyists and tourists visiting e.g. Biebrza National Park, Narwianski National Park, Stołowe Mountains National Park, Borecka Forest, or Polanow Forest District have gained access to much-extended information (often by several hundred species) about fungal species occurring in the area.

Some of my published results, apart from points and the number of citations, also gained additional recognition among scientific and forest-related groups. In 2007, my doctoral dissertation was awarded by the Scientific Council of the Institute of Dendrology of the Polish Academy of Sciences. In the same year, I also received the award of the Directorate of the Institute of Dendrology of the Polish Academy of Sciences for taking 2nd place in the competition "for the best work in 2006 with the affiliation of the Institute", and a year later the award of the Directorate of the Institute of Dendrology of the Polish Academy of Sciences for taking 3rd place in the competition "for the best work in 2007 with the affiliation of the Institute ".

The poster presentations of studies in which I participated, and which were presented by dr. Marta Kowalska-Kujawska, have met with positive reception and were awarded at the conferences:

• Conference "Trees and Forests in a Changing Environment", organized by the Institute of Dendrology of the Polish Academy of Sciences in 2016, poster: Kowalska M, Rudawska M, Stasińska M, Leski T, Karliński L. - Does forest management affect the biodiversity of mycorrhizal fungi? The competition for young scientists for the best poster presentation of results

- award of the Director of Regional Directorate of State Forests in Poznań for the 1st place
- award of the Director of the Institute of Dendrology of the Polish Academy of Sciences for the second place
- award of the Chairman of the Management Board of the Wielkopolska Department of Polish Forestry Society for the third place

• 7th International Symposium on Physiological Processes in Roots of Woody Plants (Woody Root 7), 2017, Tartu, Estonia, poster: Kujawska M, Leski T, Karliński L, Stasińska M, Rudawska M. - How forest management influence ectomycorrhizal community in continental mixed coniferous forests?

- 2nd prize in the competition for young scientists funded by the Center of Excellence "Ecology of global change: natural and manager ecosystems" (EcolChange)

• Conference "Biology and ecology of woody plants" organized by the Institute of Dendrology of the Polish Academy of Sciences in 2018, poster: Kujawska M, Karliński L, Rudawska M, Leski T. - Structure of ectomycorrhizal fungi communities on birch, hornbeam and linden seedlings in Polish forest nurseries. The competition for young scientists for the best poster presentation of results

- award of the Director of RDSF in Poznań for the second place

7. Apart from information set out in 1-6 above, the applicant may include other information about his/her professional career, which he/she deems important.

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