SHORT COMMUNICATION

Plants, fungi, and invertebrates of Northern red oak (*Quercus rubra* L.) experimental stands in Rogów Arboretum (Poland)

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ABSTRACT

This paper gives a survey of biodiversity of Northern red oak (*Quercus rubra* L.) stands in Rogów Arboretum on the background of environmental data. Northern red oak is found throughout much of the eastern United States and southeastern Canada and occurs on sites with a wide variety of soil types and topographic positions. In Poland, it is considered an invasive plant, dangerous to the native flora. During the study, 36 taxa of vascular plants, mosses, and liverworts; 40 taxa of fungi; and 112 taxa of invertebrates were found.

INTRODUCTION

Northern red oak (*Quercus rubra* L.) is widely distributed throughout much of the eastern United States and southeastern Canada. Within the natural range of this species, mean annual temperature is from 4°C in the northern part of the range to 16 °C in the extreme southern part, mean annual precipitation varies from ca. 760 mm in the Northwest to ca. 2030 mm in the southern Appalachians, and the frost-free period ranges from 100 days in the North to 220 days in the South (Sander 1965).

Red oak occurs on sites with a wide variety of soil types and topographic positions (Hills 1959). It commonly grows on mesic slopes and well-drained uplands and less commonly on dry slopes or poorly drained uplands. It grows best on lower and middle slopes with northerly or easterly aspects and in deep ravines, on soils with a thick A horizon, at elevations up to 1680 m a.s.l. (Sander 1959, 1990). Reed (1988) classified this tree as a "facultative upland."

Red oak exhibits its best growth in full sun and deep, well drained, slightly acidic, sandy loam. The most important factors determining growth conditions are the depth and texture of the A soil horizon, aspect, and slope position (Auchmoody 1979; Sander 1990). *Quercus rubra* is generally considered an early successional to mid-successional tree species (Peet and Loucks 1977). It often follows heavy disturbance such as fire. Red oak is generally unable to establish beneath its own canopy. In forest stands, red oak begins seed production at 25 years of age, but abundant seed production starts in stands that are 50 years old (Schopmeyer 1979). The relatively large acorns of red oak are usually dispersed over only short distances from the parent tree. Red oak reproduces from both seeds and root sprouts.

Seedlings usually do not reach sapling or pole size unless gaps are formed in the canopy. Light level appears to be the most significant factor affecting not only first year survival of seedlings but also survival and growth in succeeding years (McGee 1968). Germination and seedling establishment may be successful in full and partial shade, but early growth is reduced by shade, poor soil conditions, and competing herbaceous vegetation (Beck 1970; Sander 1971; Crow 1988). For example, Phares (1971) studied the growth of red oak seedlings under conditions simulating a forest understory and found that the tallest seedlings grew in 30% of full light, whereas seedlings in full light had the greatest dry weight accumulation. The successful regeneration of red oak depends more upon light availability than on any other environmental resource (Abrams 1992). According to Dey and Parker (1996), red oak requires a minimum of 20% of full sunlight before any new shoot growth occurs. However, Roberts (1991) found no significant differences in seedling growth under canopy densities ranging from 40% to 100% with the understory removed. Red oak exhibits a "stress-tolerant" conservative growth strategy as described by Grime (1979), and this strategy supports the development of a large root system prior aboveground part of the tree. Due to large root systems, the oaks are considered as a group of species quite tolerant of drought; however, red oak is one of the least drought tolerant of the upland oak species of eastern North America (Bourdeau 1959; Seidel 1972; Kleiner et al. 1992). On good sites, light is considered the most limiting environmental resource, whereas soil moisture and nutrients are more limiting on poor sites (Dey and Parker 1996). Out of its natural range, in Hungary, mean height of 80-year-old I-yield-class stands is 31 m, mean d.b.h. is 37 cm, mean stem volume is 505 m^3/ha, and basal area is 25.5 m^2/ha (Rédei et al. 2010). According to Król (1977), ca. 50-year-old stand of red oak in Poland may produce more than 450 m^3/ha of stem volume.

Under optimal conditions, northern red oak is fast-growing, and trees may live up to 500 years. Within its natural range, in undisturbed stands on good sites, mature red oak trees are usually from 20 to 30 m high and 61 to 91 cm in d.b.h. (Sander 1965). The average annual diameter increment of this species is ca. 5 mm (Gingrich 1971); however on good sites, it may be much higher (Trimble 1969).

MATERIAL AND METHODS

The study was conducted in two Northern red oak (*Quercus rubra* L.) stands with ages of 61 and 52 years, situated in the Rogów Arboretum of the Warsaw University of Life Sciences (SGGW), Poland (51°49'N, 19°53'E). The study plots (sites A and B) were located in the western and eastern parts of the Arboretum.

Table 1. The detailed information for both stands

Characteristics	Study site	
	A	B
Year of stand establishment	1948	1957
Area of experimental plot	0.04 ha	0.04 ha
Stand density (trees ha^{-1})	500	325
Stand age	61	52

According to 55 years of meteorological records from the nearest station in Strzelno, the mean annual temperature is 7.2°C (–3.2°C in January and 17.3°C in July). The mean annual precipitation is 596 mm (rang-

ing from 404 to 832 mm), around 70% of which falls during the growing season. The mean length of the growing season, defined as the number of days with a mean temperature ≥ 5°C, is 212 days (Bednarek 1993; Jagodziński and Banaszczak 2010).

The study plots are situated on flat terrain at approximately 189 m a.s.l. The soils developed on a postglacial formation within a ground moraine region. They are fertile and mesic, with the groundwater table lying below the reach of tree roots (Czępińska-Kamińska et al. 1991; Jagodziński and Banaszczak 2010). The soil unit is classified as haplic luvisol, with a sandy silt texture in the A horizon. Particle-size composition was as follows: plot A – 49% sand, 49% silt, and 2% clay; and plot B – 45% sand, 50% silt, and 5% clay. Soil pH measured in M KCl in particular horizons was as follows: plot A – Oll 4.60, Ol 5.40, Ofh 4.95, and A 3.30; and plot B – Oll 4.46, Ol 5.68, Ofh 4.85, and A 3.25. Total acidity was as follows: plot A – Oll 39.96 cmol(+)/kg, Ol 28.07 cmol(+)/kg, Ofh 38.93 cmol(+)/kg, and A 10.37 cmol(+)/kg; and plot B – Oll 43.49 cmol(+)/kg, Ol 20.52 cmol(+)/kg, Ofh 31.16 cmol(+)/kg, and A 14.18 cmol(+)/kg.

To collect samples for the presence of invertebrates, the collection methods commonly used in studies on these groups were adopted, consisting in collecting litter-soil samples with an intact structure. During three-year study (2007–2010), vascular plants, mosses, macrofungi, and soil invertebrates (nematodes, mites, and insects) were recorded and determined in the experimental plots.

Soil material for analysis was collected using a metal sampler (20 cm²). Within each study plot, 10–15 cores were taken to a depth of 15 cm. Soil from each core was divided into two horizons: (1) litter and (2) mineral soil, which were analyzed separately. From each horizon, approximately 1500–2000 cm² of material was obtained. Nematodes were extracted by centrifugation with pre-decantation, as described below.

Each sample was initially subjected to preliminary decantation in a tall vessel (25 cm high, 1 L capacity). The material was flooded and thoroughly stirred, and after 10 seconds, the suspension above the heaviest mineral particles was poured into a separate vessel. This procedure was repeated three times. The combined suspension was then sieved through a 20-μm mesh. Subsequently, the nematode suspension was centrifuged twice: first in water (2 min) and then in a 60% sucrose solution at 2500 rpm. The final product was a nematode suspension of 20 cm³. From this, subsamples of 2 cm³ were taken for faunal analysis. On this basis, nematode composition and abundance were determined and expressed per 100 cm³ of soil (Mueller et al. 2016).

In order to study mites of the order Mesostigmata and Oribatida, 10 soil samples were collected from each plot with a 20 cm². Samples were collected to a depth of 5 cm in mineral soil (also containing humus litter). Mites were removed using a Tullgren apparatus. All collected specimens of the order Mesostigmata and the order Oribatida were assigned to a species or genus (Wierzbicka et al. 2019) .

For the trapping of epigeic-soil jumping mites, the collection method commonly used in studies of this group was adopted, which consisted of taking litter-soil samples with intact structure. Samples were taken using a metal soil cannon with a diameter of 5 cm and a length of 15 cm. The area of one such sample is about 20 cm², and the depth of several centimeters allows for the collection of a sufficient amount (several centimeters) of mineral soil even in the case of a very thick layer of mulch. Studies of the communities of other soil insects were carried out using litter collected from each plot. Litter was collected from an area of 0.5 m² in three replicates in each plot. The total screening of litter and topsoil covered an area of 1.5 m² (Mueller et al. 2016). The number of described species was finally compared with the values described for the control area in Kasprowicz et al. (2011).

Results

During the study, 36 taxa of vascular plants, mosses, and liverworts; 40 taxa of fungi; and 112 taxa of invertebrates were found. The list of organisms is given below.

Vascular plants cultivated in the Arboretum, spontaneous in the investigated plots

Abies sp., *Quercus rubra* L., *Spiraea* cfr. *salicifolia* L., *Pseudotsuga menziesii* (Mirb.) Franco

Spontaneous vascular plants

Acer pseudoplatanus L., *Anemone nemorosa* L., *Carex digitata* L., *Carex pilulifera* L., *Carpinus betulus* L., *Cerasus avium* (L.) Moench, *Corylus avellana* L., *Dryopteris carthusiana* (Vill.) H. P. Fuchs, *Dryopteris fi-*

lix-mas (L.) Schott, *Euonymus verrucosa* Scop., *Fagus sylvatica* L., *Galeopsis pubescens* Besser, *Luzula pilosa* (L.) Willd., *Maianthemum bifolium* (L.) F. W. Schmidt, *Melica nutans* L., *Milium effusum* L., *Moehringia trinervia* (L.) Clairv., *Padus serotina* (Ehrh.) Borkh., *Pinus sylvestris* L., *Acer pseudoplatanus* L., *Pteridium aquilinum* L., *Quercus robur* L., *Rubus hirtus* Waldst. and Kit. Agg., *Rubus* sp., *Sorbus aucuparia* L., *Vaccinium myrtillus* L., *Veronica officinalis* L.

Mosses

Atrichum undulatum (Hedw.) P. Beauv., *Plagiothecium laetum* Schimp., *Pohlia nutans* (Hedw.) Lindb., *Polytrichastrum formosum* (Hedw.) G.L.Sm.

Liverwort

Lophocolea heterophylla (Schrad.) Dum.

Mycorrhizal fungi

Amanita citrina (Schaeff.) Pers., *Amanita fulva* Fr., *Amanita rubescens* Pers., *Boletus edulis* Bull., *Cantharellus cibarius* Fr., *Clitopilus prunulus* (Scop.) P. Kumm., *Cortinarius* cf. *casimiri* (Velen.) Huijsman, *Cortinarius* cf. *torvus* (Fr.) Fr., *Cortinarius* spp., *Laccaria amethystina* (Huds.) Cooke, *Lactarius camphoratus* (Bull.) Fr., *Paxillus involutus* (Batsch) Fr., *Rhodocollybia butyracea* f. *asema* (Fr.) Antonín Halling and Noordel., *Russula aeruginea* Fr., *Russula emetica* (Schaeff.) Pers., *Russula fragilis* (Pers.: Fr.) Fr., *Russula ochroleuca* (Pers.) Fr., *Russula vesca* Fr., *Russula* spp., *Scleroderma areolatum* Ehrenb.

Saprotrophic and parasitic fungi

Armillaria spp., *Clitocybe* spp., *Calocera cornea* (Batsch) Fr., *Crepidotus mollis* (Schaeff.) Staude, *Crepidotus* spp., *Fomes fomentarius* (L.) Fr., *Ganoderma applanatum* (Pers.) Pat., *Gymnopilus penetrans* (Fr.) Murrill, *Hapalopilus nidulans* (Pers.) Murrill, *Hygrophoropsis aurantiaca* (Wulfen) Maire, *Hypholoma capnoides* (Fr.) P. Kumm., *Hypholoma fasciculare* (Huds.) P. Kumm., *Hypholoma sublateritium* (Schaeff.) P. Kumm., *Inonotus radiatus* (Sowerby) Țura, Zmitr., Wasser, Raats and Nevo, *Lycoperdon molle* Pers., *Mycena zephirus* (Fr.) P. Kumm., *Mycena* cf. *Rubromarginata* (Fr.) P. Kumm., *Pluteus cervinus* (Schaeff.) P. Kumm., *Stereum hirsutum* (Willd.: Fr.) Gray, *Trametes versicolor* (L.: Fr.) Pilát.

Nematodes

The nomenclature was adopted according to Brzeski [32].

Cephalenchus hexalineatus (Geraert) Geraert et Goodey, *Criconema annuliferum* (de Man) Micoletzky, *Ditylenchus anchilisposomus* (Tarjan) Fortuner, *Ditylenchus* spp., *Filenchus misellus* (Andrássy) Raski et Geraert, *Filenchus discrepans* (Andrásssy) Raski et Geraert, *Filenchus vulgaris* (Brzeski) Lownsbery et Lownsbery, *Filenchus* spp., *Lelenchus leptosoma* (de Man) Mezl, *Malenchus acarayensis* Andrássy, *Paratylenchus straeleni* (de Coninck) Oostenbrink, *Paratylenchus projectus* Jenkins, *Tylenchus elegans* de Man, Aphelenchina ssp., Rhabditida ssp.

Acari (Oribatida)

Achipteria coleoptrata (Linnaeus), *Acrotritia duplicata* (Grandjean), *Ceratozetella thienemanni* (Willmann), *Chamobates pusillus* (Berlese), *Cultroribula bicultrata* (Berlese), *Galumna lanceata* (Oudemans), Juv., *Microtritia minima* (Berlese), *Moritzoppia keilbachi* (Moritz), *Oppiella nova* (Oudemans), *Oribatula tibialis* (Nicolet), *Porobelba spinosa* (Sellnick), *Quadroppia quadricarinata* (Michael), *Rhinoppia subpectinata* (Oudemans), *Suctobelbella subtrigona* (Oudemans), *Suctobelbidae* sp., *Tectocepheus velatus* (Michael).

Acari (Mesostigmata)

Leioseius magnanalis (Evans), *Leptogamasus suecicus* Trägårdh, *Macrocheles opacus* (C.L. Koch), *Nenteria pandioni* Wiśniewski et Hirschmann, *Olodiscus minima* Kramer, *Ololaelaps placentula* (Berlese), *Pachylaelaps bellicosus* Berlese, *Pachylaelaps longisetis* Halbert, *Pachylaelaps* sp. 1, *Paragamasus puerilis* Karg, *Paragamasus runcatellus* (Berlese), *Paragamasus wasmanni* (Oudemans), *Pergamasus barbarus* (Berlese), *Pergamasus brevicornis* Berlese, *Proctolaelaps juradeus* (Schweizer), *Urodiaspis pannonica* Willmann, *Urodiaspis tecta* (Kramer), *Veigaia nemorensis* (C.L. Koch), *Zercon peltatus* C. L. Koch, *Zercon* sp. 1, *Zercon triangularis* C. L. Koch.

Insects (Collembola)

Allacma fusca (Linnaeus), *Anurida granulata* Agrell, *Anurophorus* sp. juv., *Arrhopalites* sp. juv., *Ceratophysella denticulata* (Bagnall1), *Ceratophysella* sp. juv., *Desoria germanica* (Huther and Winter), *D. tigrina* (Tull-

berg), *Desoria* sp. Juv, *Entomobrya corticalis* (Nicolet), Entomobyidae juv., *Willemia anopthalma* Borner, *Folsomia lawrencei* Rusek, *F. penicula* Bagnall, *F. quadrioculata* (Tullberg), *Friesea truncata* Cassagnau, *Isotomiella minor* (Schaffer), *Lepidocyrtus lignorum* (Fabricius), *L. lignorum* gr juv., *Lipotrix lubbocki* (Tullberg), *Megalothorax minimus* Willem, *Mesaphorura hylophila* Rusek, *M. macrochaeta* Rusek, *Micranurida pygmea* Borner, *Onychiuroides granulosus* (Stach), *Onychiuroides* juv., *Parisotoma notabilis* (Schaffer), *Pogonognatellus flavescens* (Tullberg), *Proisotoma minima* (Tullberg), *Pseudachorutes dubius* Krausbauer, *Pseudachorutes* sp. juv., *Pseudosinella alba* (Packard), *P. horaki* Rusek, *Schoetella ununguiculata* (Tullberg), *Sphaeridia pumilis* (Krausbauer), *Sminthurinus* sp. Juv, *Tomocerus minor* (Lubbock), Tomoceridae juv.

Insects (Coleoptera)

Altica quercetorum (Foudras), *Agonum assimile* (Payk.), *Amara familiaris* (Duft.), *Apion* sp., *Athous niger* L., *Calathus melanocephalus* (L.), *Cantharis fusca* L., *Carabus granulatus* L., *Carabus hortensis* L., *Carabus nemoralis* O.F.Muller, *Harpalus affinis* (Schrank), *Lema melanopus* L., *Melolontha melolontha* L., *Sitona* sp., *Propylea quatuordecimpunctata* L., *Pterostichus niger* (Schall.), *Pterostichus diligens* (Sturm), Staphylinidae ssp., *Strophosoma capitatum* (DeGeer), Tipulidae spp.

Other insects

Homoptera spp., Heteroptera spp.

Table 2. Comparison of the number of taxa described in the *Q. rubra* stand and in the control plot (*Tilio-Carpinetum*)

	Quercus rubra	*Tilio-Carpinetum* (Kasprowicz et al. 2011)
Spontaneous vascular plants + mosses	36	52
Fungi	40	67
Invertebrates	112	162

Discussion

In Poland, red oak is considered an invasive plant, dangerous to the native flora. During the study, 36 taxa of vascular plants, mosses, and liverworts were found, which is considerably fewer than the control plot (*Tilio-*

Carpinetum), which contained 52 taxa (Kasprowicz et al. 2011). In the present study, a total of 40 fungal taxa were described: 20 mycorrhizal and 20 Saprotrophic or parasitic fungi. Interestingly, among the ectomycorrhizal fungi, neither *Cenococcum geophilum* nor fungi of the genus *Telephora*, which are commonly associated with red oak, were found. However, taxa from two other fungal genera associated with red oak were recorded: *Russula* spp. (6 taxa) and *Cortinarius* spp. (3 taxa) (Trocha et al. 2012; Dyderski et al. 2020).

The study of soil fauna associated with red oak microhabitats in the Rogów Arboretum revealed a total of 52 species belonging to the mesofauna. In the case of nematodes, 15 taxa were described. As indicated by Mueller et al. (2012), nematodes occurring in the soil under red oak showed the lowest species richness among the eight studied deciduous species, and this parameter decreased with increasing soil acidity. As studies by other authors indicate, soil pH under red oak is lower than under native oak species; however, a more significant predictor may be the higher C/N ratio of red oak litter limiting the soil microbial activity (Mueller et al. 2012; Stanek and Stefanowicz 2019).

Stanek and Stefanowicz (2019) conducted studies on the communities of oribatid mites (Acari: Oribatida) in Polish commercial forests and have revealed a negative impact of red oak on soil fauna. They reported the small proportion of Oribatida species significantly distinguished old alien oaks from old native oaks. Our research confirmed the results of the authors mentioned above. The Oribatida fauna in the red oak stands is represented by 16 taxa, which is significantly less than in the stands of other alien tree species cultivated in the Rogów Arboretum, for example, *Abies grandis* (40 taxa) (Skorupski et al. 2011), *Abies cephalonica* (45 taxa) (Jagodziński et al. 2011), *Abies procera* (39 taxa) (Kohyt and Skubała 2020), and *Pinus peuce* (50 taxa) (Jagodziński et al. 2011). Similar general conclusions are drawn from the work of Mueller et al. (2016): evergreen tree species were characterized by higher average taxon richness in the case of Oribatidae mites. The negative impact of red oak compared to native oak species is less pronounced or absent for predatory mites of the order Mesostigmata (Urbanowski et al. 2021). This order was represented in the present study by the largest number of species among the entire mesofauna – 21 taxa. The largest number of taxa belonged to the families Parasitidae

(6 taxa), Zerconidae (3), and Pachylaelapidae (3), which are commonly found in soil environments (Gwiazdowicz et al. 2006). Of all the taxa described, four belonged to the suborder Uropodina. Some species are common in a wide variety of habitats (e.g., *Olodiscus minima*) (Błoszyk et al. 2004), while others, such as *Nenteria pandioni*, occur less frequently and are typical of habitats like predatory bird nests (Błoszyk et al. 2006).

Springtails were the most numerous group in terms of species richness, with 38 species recorded. Woziwoda et al. (2012) point out that Collembola springtails proved useful for assessing the effects of the introduction of alien species. In the areas with *Quercus rubra*, the density of individuals per 1 m^2 was reduced by as much as half (Sławska 2005, 2006). The reduction in species richness and diversity of springtail communities occurs primarily at the expense of endemics (Deharveng 1996) and specialized species (Sławska 2005, 2006), which are crucial for preserving the diversity and native character of fauna. However, in the case of crops occupying small areas and located in the vicinity of autochthonous stands, the average densities and species richness of Collembola communities were very similar, which may indicate the ability of native fauna to effectively colonize the plantation area (Fjellberg et al. 2007; Kovac et al. 2005). From our studies in the Rogów Arboretum, we can conclude that the number of Collembola taxa did not differ significantly from the average observed in other areas. This conclusion contradicts Mueller et al. (2016) results, according to which red oak had a clear positive effect on the taxon richness of springtails compared to 13 other deciduous and coniferous species. This was probably influenced by the thickness of the organic layer on the forest floor.

Most of the described taxa of the order Coleoptera belonged to the family Carabidae (9 out of 20). This group of ground beetles is common in every climate zone, feeding on both plant and animal foods (Lövei and Sunderland 1996).

Acknowledgments

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