sciendo

Folia Forestalia Polonica, Series A – Forestry, 2019, Vol. 61 (1), 51–57

ORIGINAL ARTICLE

DOI: 10.2478/ffp-2019-0005

Scots pine *Pinus sylvestris* mortality after surface fire in oligotrophic pine forest *Peucedano-Pinetum* in Kampinos National Park

Łukasz Tyburski[1] ✉, *Piotr T. Zaniewski*[2], *Leszek Bolibok*[3], *Mateusz Piątkowski*[4], *Andrzej Szczepkowski*[5]

[1] Kampinos National Park, Department of Science and Nature Monitoring, Tetmajera 38, 05-080 Izabelin, Poland, email: ltyburski@kampinoski-pn.gov.pl

[2] Warsaw University of Life Sciences – SGGW, Faculty of Forestry, Department of Forest Botany, Nowoursynowska 159, 02-776 Warsaw, Poland

[3] Warsaw University of Life Sciences – SGGW, Faculty of Forestry, Department of Forest Silviculture, Nowoursynowska 159, 02-776 Warsaw, Poland

[4] Warsaw University of Life Sciences – SGGW, Faculty of Forestry, Forestry Students' Scientific Association, Nowoursynowska 159, 02-776 Warsaw, Poland

[5] Warsaw University of Life Sciences – SGGW, Faculty of Forestry, Department of Forest Protection and Ecology, Nowoursynowska 159, 02-776 Warsaw, Poland

Abstract

Pines are generally fire-resistant trees. There is a shortage of research on the behaviour of Scots pine after surface fire in older stands. The aim of the work was to describe the effect of the surface fire intensity on the mortality of pines of various diameter at breast height (DBH), including older trees. The research was conducted in *Peucedano-Pinetum* oligotrophic Scots-pine forest in Kampinos National Park (KPN, central Poland) on the area of two adjacent surface fire sites originated in spring 2015 in 60- to 200-year-old stands (site area: 10,92 ha). There were 45 (28 burned and 17 control) permanent plots established after the fire. The share of not burned, superficially burned and completely burnout organic horizon of the soil was determined within all of them. DBH and location of pine trees were measured within all of the plots on the area of 200 m^2. For all of the trees for which full information about soil organic horizon damage was mapped, the prevailing type of disturbance in their close neighbourhoods with radii of 1 and 2 m was assessed. The mortality of trees was assessed after each vegetation period up to 2017, basing on the presence of green needles on the trees. The influence of fire intensity on the survival of trees was examined on whole permanent plot level as well as on individual tree level. Strong linear correlation was observed between Scots pine mortality and the share of plots area with damaged organic layer, especially at the end of the third vegetation period after fire. Logistic regression models constructed for individual trees suggest that bigger tree diameter (hence, thicker bark) diminished the odds of mortality only after two vegetation periods from the fire. After the third vegetation period, only the intensity of surface fire in the close neighbourhood of trees influenced (negatively) the chance on survival. The size of trees did no matter in this case. Nearly all of the trees that were located within burnout organic matter areas died. The results did not support the commonly known mechanism of enhancement of bigger Scots pine tree survival after surface fire because of thicker bark responsible for heat protection. Probably, the main cause of observed mortal-

Received 23 October 2018 / Accepted 15 November 2018

ity was not overheating of cambium but it was rather connected to massive fine root loses. Scots pines growing on oligotrophic arid sites modify their root system to explore topsoil layers with higher proportion of shallow roots, growing even in organic litter layer. This corresponds with massive (regardless of size) pine mortality within sites characterised by complete burnout of organic matter layer and very high survival in those ones with only surfacely burned litter layer. The results can improve the assessment of surface fires consequences in managed Scots pine stands growing in oligotrophic conditions.

Key words

burn, Kampinos National Park, Scots pine, survival

Introduction

Species of pine from *Pinus* genera are relatively resistant to fires (Fernandes et al. 2018). This also applies to Scots pine *Pinus sylvestris*. The reaction of this species to fire has been the subject of many studies, especially in the north of Europe (i.a. Niklasson, Granström 2000; Niklasson, Drakenberg 2001). These studies show that larger specimens of pine are characterised by increased resistance to fire, for example, because of higher crowns, larger diameter of trunk and thicker bark, which is a good insulation against high temperatures during fire (Sidoroff et al. 2007; Fernandes et al. 2008). Increased mortality of large pine trees was found in the case of presence of open scars after previous fires. In this situation, another fire may cause the burning of the middle part of the trunk and thus the death of trees (Linder et al. 1998). There is insufficient data on damage caused by fires in forest stands in the old forest stage. The reason for this is, amongst others, the small share of tree stands in this phase of development and thus the rarity of potential research objects. The way of dealing with forest stands after fires is an important issue from the point of view of forestry (i.a. Olejarski 2003; Wiler and Wcisło 2013; Mocek-Płóciniak et al. 2016). Ground fires may cause long-term silviculture consequences for damaged stands, weakening trees and increasing their mortality in a later period. Pine forests belong to the forest communities that are most vulnerable to fire (Ubysz et al. 2012).

The aim of this work was to assess the impact of surface fire intensity and tree diameter on the Scots pine tree survival during the first three vegetation periods after the surface fire in the *Peucedano-Pinetum* W. Mat (1962) 1973 oligotrophic Scots pine forest, which occurred in spring 2015. The research was carried out within the diversified age pine stands in the Kampinos National Park (KPN, central Poland).

Material and methods

The Kampinos Forest lies in the areas of two dune belts and two marsh belts. The dune belts are built of sands formed in the dunes in the Holocene era. Geological formations in the dune belt area are built of loose sands. Rusty and podzolic soils predominate there (Sikorska-Maykowska 2003). Old-forest stands in KPN occur mainly on dune belts (Szczygielski 2002). The KPN was included in the highest (first) fire hazard category in Poland. About 57% of fires that take place in all national parks in Poland occurs there (Szaga 2015).

The research area was located in the eastern part of the southern dune belt of KPN. It was placed within seven Scots pine forest stand that are 60 to 200 years old. The part of the forest was damaged by two surface fires in the late spring (7 May and 4 June, in the period of the highest level of fire hazard) of 2015. The total burned area covered 10.92 ha of the plant community *Peucedano-Pinetum* – oligotrophic *Vaccinium* type of Scots pine forest. The stands originated on rusty and rusty podzolic soils with moder-mor humus type developed on poor loose sands (Olejniczak et al. 2017).

The set of 45 permanent plots was established in the research area in 2015 (28 plots in the fire disturbed sites and 17 control sites adjacent to the surface fire area). The level of burnout of organic matter horizon was mapped within all of the fire disturbed plots.

Three levels of disturbance were distinguished: undisturbed by fire, partially burned (with burned forest floor plants and partly burned organic matter horizon) and completely burned (total burnout of forest floor plants and organic matter horizon, only ash remained). Detailed methodology of burned organic matter mapping was presented in the work by Zaniewski and Otręba (2017).

On each plot the diameter at breast height (DBH) of all trees was measured on the 200 m^2 area. For all of the trees for which full information about soil organic horizon damage was mapped, the prevailing type of disturbance in their close neighbourhoods with radii 1 and 2 m was assessed. The survival of pines was noted after the vegetation periods in the years 2015–2017. Some severely injured pines (without bark on the trunk cir-

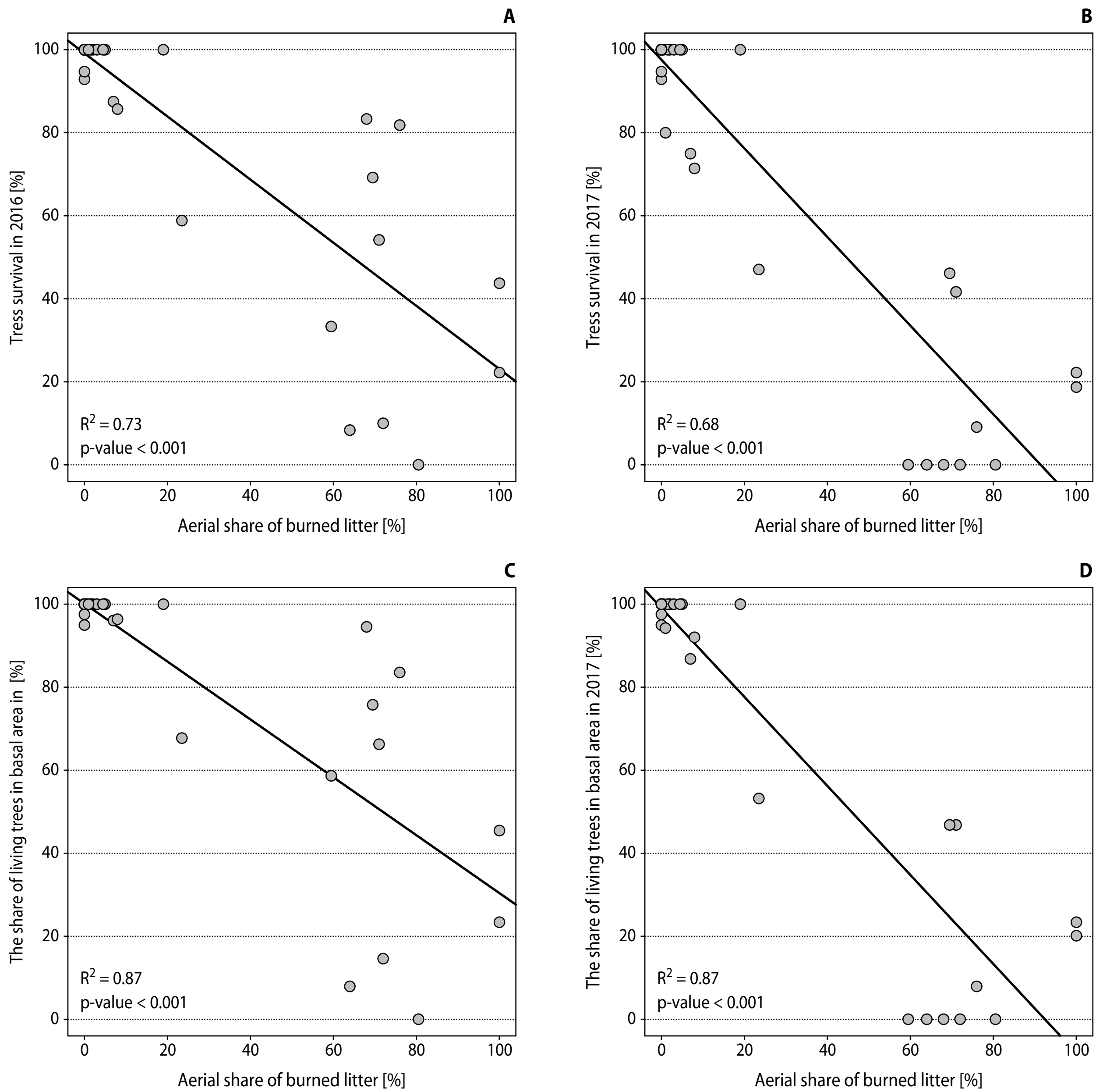

Figure 1. Relationship between the tree survival in 2016 (A) and 2017 (B), the share of living trees in basal area in 2016 (C) and 2017 (D) and aerial share of burned litter

cumference at the breast height) still have green needles after first growing season. Owing to this fact, the distinction on dead and alive trees was based on the presence of green needles (i.a. Linder et al. 1998; Sidoroff et al. 2007). Taking such assumption into consideration, at the end of the first growing season (year 2015), all trees on plots damaged by surface fire were assessed as alive, and therefore, the mortality was observed only after the second and third vegetation periods in 2016 and 2017.

Statistical analysis was performed on two spatial scales: permanent plot level and individual tree level. At the level of permanent plot, the relationship between the share of leaving tress as well their share in forest stand basal area and the share of the totally burnout organic matter was checked using the linear regression method.

The influence of DBH and the level of organic horizon disturbance in close tree neighbourhood on its survival was determined using the logistic regression method.

Two radii of close neighbourhood (1 and 2 m) were investigated in separate models. Four analyses were carried out separately by taking both the ends of growing seasons in the years 2016 and 2017 and two spatial scales into account. Statistical analyses were performed using the PAST (Hammer et al. 2001) and R (R Core Team 2018) software.

Results

There were 451 pine trees sampled all together within 45 permanent plots. Their DBH median was 22.6 cm (minimum, 11.1 cm; Q1, 19.0 cm; Q3 – 29.5 cm; maximum 61.4 cm). The relationships between the percentage share of trees that survived the fire (Fig. 1A, 1B) or the share of living tress in forest stand basal area (Fig. 1C, 1D) and the area with completely burned organic layer horizon assessed at the level of sample plots were statistically significant. The stronger dependence (higher R^2 coefficient) was recorded for the year 2017 models (survival after the third growing season after the fire).

At the level of a single individual, the survival of pines at the end of the second growing season in the year 2016 was correlated negatively with increasing level of organic horizon disturbance and positively with larger tree DBH. However, survival at the end of the third growing season of the year 2017 was dependent only on local disturbance intensity and the positive influence of larger DBH of the trees turned out to be non-significant (Tab. 1). High values of the AUC indicator show that the constructed models had very good or good prognostic ability (Tab. 1). The results obtained for the models of both 1 and 2 m from the centre of the trees were convergent but the survival at the end of the second growing season in the year 2016 was slightly better predicted when taking into account level of organic soil horizon disturbance in closer (1 m) neighbourhood.

Table 1. Variables influencing Scots pine survival (models A and C – 1 m radius from centre of trees, models B and D – 2 m radius from centre of trees, models A and B – after one year, models C and D – after two years)

Model Id	AUC Area under curve	Important variables	Regression coefficients	p-value	OR
A	0,9211	diameter at the breast height	0,15904	0,0092	1,17
		level of organic layer horizon disturbance	3,86317	0,0000	47,62
B	0,9013	diameter at the breast height	0,15452	0,0101	1,17
		level of organic layer horizon disturbance	3,50058	0,0000	33,13
C	0,8542	level of organic layer horizon disturbance	3,5553	0,0000	35,00
D	0,8552	level of organic layer horizon disturbance	3,5582	0,0000	35,10

Discussion

Surface fire can cause damage to the cambium of pines, which results in characteristic fire scars at the base of the trees (Parviainen 1996). Later, such scars may be the cause of increased mortality of trees as a result of subsequent fires, amongst others, because of the possibility of fire access to the interior of the trees and burning out of the wood in the trunks (Linder et al. 1998). The studied young and old-growth pine stands were characterised by the lack of open fire scars and the very rare occurrence of other damages that could allow the trunks to burn out from the inside. This observation allowed to assume that above-mentioned damaging mechanism was most probably of limited importance in the mortality of the studied pines.

Probable cause of observed pine mortality could be damage to their root system. Scots pine develops more fine roots on poor soils (Vanninen and Mäkela 1999) and their increased weight under oligotrophic conditions is needed to maintain an optimal amount of assimilation apparatus (Helmisaari et al. 2007). The biomass of fine roots of this species is also greater in sites with a higher carbon-to-nitrogen ratio in soil humus (Finer et al. 2007). The largest shallowing of the pine root system is noted in the poorest soils (Przybylski 1970). The density of fine roots in the organic soil horizon in such conditions may be even higher than that in the mineral horizons (Vanninen and Mäkela 1999). The largest part of ectomycorrhizas can also be located in the organic soil layer (Smirnova et al. 2008). The patches of both young and old-growth pine stands within the studied fire site are located on poor rusty soils (WBR: Brunic and AlbicBrunicArenosols) developed from loose sands with moder-mor organic horizon (Olejniczak et al. 2017). Owing to this fact, the oligotrophic nature of the substrate most likely influenced the location of most of the small pine roots within the organic soil horizon and its contact with the topsoil horizons. In the parts of the research site affected only by burning of the upper part of the organic layer horizon, the pine trees were characterised by very low mortality. In the parts characterised by total burnout of the organic layer horizon, the pine mortality recorded after 2 years was almost complete (Fig. 1).

The influence of DBH and its bark insulation capacity on pine survival (Sidoroff et al. 2007; Fernandes et al. 2008) was recorded only after second vegetation period from the time of fire disturbance (Tab. 1a, b). However, this dependence was not confirmed after three vegetation periods from the disturbance (Tab. 1c, d). This means that the DBH was only of temporary importance, and the mortality of trees after the third vegetation period from the fire had a different cause. The mechanism leading to the weakening and subsequent death of trees on the analysed post-fire site was not usually the overheating of the base of the stump combined with cambium death (Parviainen 1996). The above conclusion is also indicated by the slight fire damages of the trunk base of the most of the studied trees, as well as the high survival rate of pines in the conditions of only partial burning of the organic layer horizon in the vicinity of the trunks. High correlation of pine mortality with percentage share of completely burnout organic soil horizon at the level of sample plots (Fig. 1) or its domination at the level of a single individual (Table 1) indicates that the main reason of further death of pines was direct damage to the shallowly located parts of the pine root systems by fire.

The studied pines were not killed by fire directly. The disturbance caused their considerable weakness. The trees have been dying gradually for three following vegetation periods. The direct effect of the fire on the organic horizon may be the reduction in the number of small roots of the pine tree up to one-third and the reduction or even disappearance of ectomycorrhizae (Smirnova et al. 2008). It is highly probable that the damaged roots of the researched pines could be effectively attacked by various pathogens, for example, a dangerous pathogen of the root system– *Heterobasidion annosum* Fr. (Bref.), whose basidiomata were found in the roots of overturned trees on the studied fire site. The observed abundant fruiting of *Rhizina undulata* Fr., a non-obligatory pyrophilic fungus, could also weaken the roots of old pines (Sierota 1998, 2001). As a result of the fire, the occurrence of many other species of pyrophilic fungi as well as species considered to be the pathogens of pine were observed in the area of the investigated site (Gierczyk et al. 2017, 2019). Pine trees proportionally allocate much larger amounts of energy in quick reconstruction of lost in fire parts of the root systems. Owing to this reason, the rate of new root formation in disturbed sites does not differ from the rate of root growth in undisturbed conditions (Smirnova et al. 2008). Weakened by fire and allocation of resources, pines could become more vulnerable to insect attacks. There was an abundant occurrence of *Phaenops cyaneus* (Fabricius 1775) registered in the researched pine stands after the fire (Dawid Marczak, pers. commun.). This species is considered to be a secondary pest of pines (Stocki et al. 2008). Its occurrence could cause additional weakening of pines within most disturbed patches. The insects feeding under the bark of pines were intensively mined by woodpeckers, which, in search of insects, stripped large parts of bark from the trunks of weakened trees. As a result, the pines finally died.

The higher DBH only temporarily increased the possibility of tree survival within the study site. The percentage share of burnout within organic matter horizon profile is used in order to assess the possibility of future pine mortality within post-fire stands in Poland (Wiler and Wcisło 2013). The highest disturbance is connected to the mortality of more than 30% of pines. According to the obtained results, pine mortality within most disturbed, oligotrophic sites can reach even 100% of the individuals. It can happen also in the oldest – 200 year old – parts of the stands grown by the thick pine trees. The share of the surface with completely burned organic soil horizon also seems to be a good indicator for determining the possible survival of pines on oligotrophic soils (Fig. 1).

Summary and conclusions

– There was a significant increase in the probability of pine mortality associated with the increase in the disturbance by surface fire, measured as the share of completely burned organic soil horizon at the permanent plot level as well as its domination in the nearest surrounding of the tree (up to 2 m) at the tree individual level.
– All of the trees stayed alive at the end of first vegetation period, the thickness of the tree had a positive effect on the increase in the probability of survival of the tree only after the second vegetation period; in the perspective of three vegetation periods, this variable no longer had any significance.
– The old-growth pine stands reaction was most likely influenced by shallow rooting of trees in oligotrophic soil, resulting in the destruction of that part of root system; this mechanism lead to considerable weakening of pines regardless of their diameter; their direct death occurred within 2 years after the fire, which was probably caused by the loss of mycorrhiza, fungal infections and insect activity – secondary pests.
– It is possible to predict the effects of the surface fires on pine stands growing on oligotrophic soils, based also on the degree of burnout of the organic matter horizon, which can be taken into account whilst estimating losses after surface fires in such habitats.

Acknowledgements

The research was carried out as part of the research topic ‘Physical, chemical properties of soils, diversity of plant, fungi and micro fauna in Palmiry post-fire site in the Kampinos National Park – stage II’ co-financed from the Forest Fund of PGL Lasy Państwowe State Forests in 2017.

References

Fernandes, P.M., Vega, J.A., Jiménez, E., Rigolot, E. 2008. Fire resistance of European pines. *Forest Ecology and Management*, 256, 246–255.

Finér, L. et al. 2007. Variation in fine root biomass of three European tree species: beech (*Fagus sylvatica* L.), Norway spruce (*Picea abies* L. Karst.), and Scots pine (*Pinus sylvestris* L.). *Plant Biosystems*, 141 (3), 394–405.

Gierczyk, B., Szczepkowski, A., Kujawa, A., Ślusarczyk, T., Zaniewski, P. 2017. Contribution to the knowledge of fungi of the Kampinos National Park (Poland) with particular emphasis on the species occurring in burnt places. *Acta Mycologica*, 52 (1), 1093. https://doi.org/10.5586/am.1093

Gierczyk, B., Szczepkowski, A., Kujawa, A., Ślusarczyk, T. 2019. Contribution to the knowledge of fungi of the Kampinos National Park (Poland). Part 2. *Acta Mycologica*, 54 (1), 1116. https://doi.org/10.5586/am.1116

Hammer, Ø., Harper, D. A.T., Ryan, P.D. 2001. PAST: Paleontological Statistics software package for education and data analysis. *Paleontologia Electronica*, 4 (1), 1–9.

Helmisaari, H.S., Derome, J., Nöjd, P., Kukkola, M. 2007. Fine root biomass in relation to site and stand characteristics in Norway spruce and Scots pine stands. *Tree Physiology*, 27, 1493–1504.

Linder, P., Jonsson, P., Niklasson, M. 1998. Tree mortality after prescribed burning in an old-growth Scots pine forest in northern Sweden. *Silva Fennica*, 32 (4), 339–349.

Mocek-Płóciniak, A., Bielińska, E.J., Wolna-Murawka, A., Futa, B. 2016. Effect of the revitalisation method on microbial activity of soils 20 years after the complete burn-out (in Polish with English summary). *Sylwan*, 160 (3), 247–255.

Niklasson, M., Granström, A. 2000. Numbers and sizes of fires: long-term spatially explicit fire history in a Swedish boreal landscape. *Ecology*, 81 (6), 1484–1499.

Niklasson, M., Drakenberg, B. 2001. A 600-year tree-ring fire history from Norra Kvills National Park, southern Sweden: implications for conservation strategies in the hemiboreal zone. *Biological Conservation*, 101 (1), 63–71.

Olejarski, I. 2003. The influence of agrotechnical treatments on some of soils properties and the condition of Scots pine forest regeneration on great post fire areas (in Polish with English summary). *Prace Instytutu Badawczego Leśnictwa, Seria A*, 2 (952–955), 75–77.

Olejniczak, I. et al. 2017. Fire – a factor forming the numbers of microorganisms and mesofauna in forest soils (in Polish with English summary). *Annual Set The Environment Protection*, 19, 511–526.

Parviainen, J. 1996. Impact of fire on Finnish forests in the past and today. *Silva Fennica*, 30 (2/3), 353–359.

Przybylski, T. 1970. Morphology. In: Scots pine *Pinus sylvestris* L. Nasze drzewa leśne (in Polish) (ed.: S. Białobok). PWN, Warszawa–Poznań, 86–123.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/

Sidoroff, K., Kuuluvainen, T., Tanskanen, H., Vanha-Majamaa, I. 2007. Tree mortality after low-intensity fires in managed *Pinus sylvestris* stands in southern Finland. *Scandinavian Journal of Forest Research*, 22 (1), 2–12.

Sierota, Z. 1998. *Rhizinaundulata* on stem and roots of 84-year-old Scots pine trees. *Acta Mycologica*, 33 (1), 69–76.

Sierota, Z. 2001. Forest diseases (in Polish). CILP, Warszawa.

Sikorska-Maykowska, M. 2003.Geological structure. In: Kampinos National Park – nature Kampinos National Park. Tom 1 (in Polish) (ed.: R. Andrzejewski), 69–86.

Smirnova, E., Bergeron, Y., Brais, S., Granström, A. 2008. Postfire root distribution of Scots pine in relation to fire behaviour. *Canadian Journal of Forest Research*, 38, 353–362.

Stocki, J., Kinelski, S., Dzwonkowski, R. 2008. Conifers and insects feeding on them. Guide for a forester (in Polish). Multico, Warszawa.

Szaga, W. 2015. The eye of a park employee (in Polish). *Przegląd Pożarniczy*, 9, 5–17.

Szczygielski, M. 2002. Operat ochrony ekosystemów leśnych na okres 01.01.2002 r. – 31.12.2021 r. Volume I. Biuro Urządzania Lasu i Geodezji Leśnej, Warszawa.

Ubysz, B., Szczygieł, R., Kwiatkowski, M., Piwnicki, J. 2012. Forest fire protection instructions (in Polish). Centrum Informacyjne Lasów Państwowych, Warszawa.

Vanninen, P., Mäkela, A. 1999. Fine root biomass of Scots pine stands differing in age and soil fertility in southern Finland. *Tree Physiology*, 19, 823–830.

Wiler, K., Wcisło, P. 2013. Protection of forests against fires (in Polish). Centrum Informacyjne Lasów Państwowych, Warszawa.

Zaniewski, P.T., Otręba, A. 2017. Response of vegetation to the surface fire in the pine forest *Peucedano−Pinetum* W. Mat. (1962) 1973 in the Kampinoski National Park (in Polish with English summary). *Sylwan*, 161 (12), 991–1001.