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EFFECTS OF SURFACE FIRES ON SCOTS PINE FORESTS OF THE POLISKYI NATURE RESERVE

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Abstract

The study presents the assessment of fire effect produced by surface forest fires on the herbal plants, the possibility of natural forest regeneration and Scots pine stands of the Poliskyi Nature Reserve. Five-year succession of forest herbs following the fire of 2009 was evaluated by analyzing its species' composition, coenotic structure, similarity, constancy and dominance of species in the burned area and comparison with similar unburned forest. The consequences for herbal plants mostly depend on the type and intensity of a wildfire. The response of the herbal layer to fire factor varies from small revertible short-term changes to degradation or even complete distinction. Surface fires stimulate emergence of Scots pine regeneration. On stand level, fires cause the deterioration of trees' health and the reduction of stand growth. The mathematical model for severity of fire and tree health was developed.

Key words: fire severity, natural regeneration, post-fire succession, species diversity, species similarity, surface fire.

Introduction

Global climate change results in growth of intensity and areas of wildfires globally that, in turn, are drivers of significant changes in forest ecosystems and other types of landscapes (Pyne 1997, 2010; Goldammer et al. 2013). Nowadays there is a clear trend of wildfires increase that often becomes catastrophic in Australia, Greece, Portugal, Russia, Spain, USA, and other countries (Goldammer et al. 2013, Heyerdahl et al. 2014, Axelson et al. 2019, Lynn 2019, Roper 2020). Ukraine is no exception, in the first six months (January-June) 2020 in different landscapes of the country there were more than 1 thousand wildfires on a total area of more than 110,000 ha, of which 67,000 ha are in the Chernobyl Exclusion Zone (Zibtsev and Myroniuk 2020). Protected areas are most vulnerable to fires in Ukraine. During the last six years 27 % of the burned areas in the northern region of Polissya have been nature reserves, the total burned area accounting for 87,500 ha (Gumeniuk 2015; Zibtsev and Myroniuk 2015, 2020). Under conditions of fire risks and burned areas growth it is important to have reliable data on the impact of fires on such important components as herbal plans, stand and regeneration.

Historically fires have been one of the important factors that determined biodiversity, composition and age structure of stands, vegetation dynamics and the biological cycles in forests (Goldammer and Furyaev 1996; Pyne 1997, 2010). Studies of post-fire dynamic in other regions of the world show that it is determined by the type of wildfires and their intensity (Furiaev et al. 2005, Kane et al. 2012, Lauvaux et al. 2015, Meng et al. 2015). After crown and peat fires, pine stands are completely destroyed as a result of the damage to their crowns and root systems (Hyrs 1973, Valendik et al. 2013). Post-fire dieback of trees after surface fires can vary essentially (5–100 %) which depends on fire dynamics and which in turn poses difficulties for the prediction of trees' survival rate. The trees' dieback after surface fires depends on the characteristics of forest components, for example, forest structure, age, height and diameter of trees, edaphic conditions and seasonal dynamics of wildfires (Usenia 2000, Furiaev et al. 2005, Hordei 2007). The wildfires in fire dependent ecosystems determine the spatial structure of the stands and changes on the landscape level, including the expansion of Scots pine (Hille 2006, Sokolov et al. 2011, McIver et al. 2012). Dendrochronological studies of ancient trees in the United States (Stocks et al. 2001) show that the recurrence of large fires can range from tens to hundreds of years.

Controlled fire can be used as a tool for shaping stand structure and dynamics close to a natural way within approaching sustainable forest management targets (Goldammer et al. 2013, Battipaglia et al. 2014, Douglas et al. 2015). Prescribed fires, widely used in the world, allow the stimulation of natural forest regeneration in order to obtain productive and sustainable stands in the future. In a similar study, Sannikova (1977, 1978) notes increased productivity of Scots pine seeds after surface fires and favourable conditions for the emergence of a new forest generation.

The impact of wildfires on the herbal plants underneath forest cover has been studied for more than a century, but mainly outside Ukraine (Clements 1910, Zhytlukhyna and Shubenko 2002). Perevoznykova et al. (2005), Kovaleva and Ivanova (2013) found out that surface fires of low- to medium-intensity do not cause significant changes in the phytocoenosis, however, high-intensity fires can lead to prolonged succession of forest herbs. Another paper (Rabotnov 1978, Sakhnevych 2005) showed that in wet edatopes the herbs-moss cover recovers faster (3–5 years) than in dry ones (10–15 years), which significantly reduces the time of post-fire transformation of vegetation. Summarizing, it is necessary to state that the impact of surface fires on the forest dynamics in Ukraine has not been studied in detail and the existing studies (Gumeniuk 2013, 2015; Gumeniuk et al. 2015, Voron et al. 2017) are fragmented.

Therefore, this paper aims to study the effect of surface fires on the components of Scots pine forests such as forest ground vegetation, natural forest regeneration, and structural changes in the affected stands. The results will provide better understanding of the pyroecological properties of pine forests.

Material and Methods

Study area

The research was carried out in the Scots pine stands of Poliskyi Nature Reserve located in Zhytomyr region of Ukraine (North of the country), affected by different intensity surface fires in May 2009 (Fig. 1). The total area of the wildfires is over 1000 ha.

The experimental data were collected on 32 plots, including 18 plots in burned forest and 14 plots in unburned territories. The study is based on the approach of comparative ecology (Pogrebnyak 1993), under which the main parameters of similar by structure burned and unburned (control) forest were compared. The plots of burned forest were divided into three groups based on the intensity of the surface fires and the scorch height (S_{height}) on a tree trunk (Cabinet of Ministers of Ukraine 1995): low (S_{height} < 0.5 m), medium (S_{height} 0.5–1.5 m) and high (S_{height} > 1.5 m).

Input datasets

Dataset to assess the surface fires effect on the forest ground vegetation

The method described by Chasovenna (1975) was used in the framework of the research. Twenty 1×1 m subplots on each of 32 plots were selected. The species' composition, their projective cover, abundance and type (herbs-shrub, moss, lichens) were studied on both burned and unburned plots. The Myrkyn and Rozenberh (1978) asymmetric unequal distance scale was used to establish the abundance of plant species: + (up to 1 %), 1 (1–5 %), 2 (5–15 %), 3 (15–25 %), 4 (25–50 %), 5 (50–100 %). The indicators of dominance, constancy and species similarity were calculated.

Fig. 1. Study area.

The constancy of species was determined as a percentage, namely as the ratio of the number of the sites where these species occur, to the total number. The species' dominance is defined as the ratio of its projective cover sum to the site number on which this species was found (Chasovenna 1975).

The Jaccard similarity index was calculated by the formula:

$$K_j = \frac{c}{a+b+c}, \quad (1)$$

where:

K_j is the Jaccard similarity index;

a is the number of species in the first site (1×1 m);

b is the number of species in the second site (1×1 m);

c is the number of species common to the first and second sites.

Soil conditions were determined according to the forest types classification of Alexeev-Pogrebnyak (Pogrebnyak 1955) generally used in Ukraine. The soil conditions were analyzed according to two factors: soil fertility (A–D) and soil moisture (0–5). The degree of soil fertility and moisture was established based on the number of species present in a site. The coenotic structure of the herbal layer was studied based on Belhard's (1955) system of life forms (ecomorphs), which includes the following groups: Sil – forest species, St – steppe species, Pr – meadow species, Pal – wetland species, Ru – invasive species. The nomenclature of forest herbs and their taxonomy was determined using the international plant database (The Plant List … 2013) and the Determinants of plants of Ukraine (Barbarich et al. 1965).

Dataset to assess the surface fires effect on the natural forest regeneration

The natural forest regeneration was studied according to Pobedinsky's (1966) method on 10 2×2 m subplots (total 320 micro plots). Age, height and the number of trees undergoing natural regeneration were measured on both burned and unburned parts. The undergrowth age was determined by counting the whorls. Two years was added to the undergrowth to allow for the time between seedling germination and the evidence of branch whorls on the trunk. The height of the undergrowth was divided into groups: up to 10 cm, 11–25 cm, 26–50 cm, 51–100 cm, 101–150 cm; 151–200 cm; > 200 cm.

The success of natural forest regeneration and the Scots pine constancy were determined as the ratio of the number of sites where this species occurs to the total number of sites. Regeneration success was measured according to Gorshenin's scale (Gorshenin and Shvidenko 1977).

The vital energy of seedlings and undergrowth was classified into the following categories: healthy, weakened, drying out and dried. The viability of coenopopulation's regeneration was determined by the ratio of every category. The viability index of coenopopulation was calculated according to Alekseev (Ivanova et al. 2002):

$$L = \frac{100n_1 + 70n_2 + n_3}{N}, \quad (2)$$

where:

L is the relative viability of the coenopopulation;

n_1, n_2, n_3 are the numbers of healthy, weakened and drying out individuals on the temporary sample plots (TSPs) or per ha;

N is total number of undergrowth individuals, including dried, on the TSPs or per one ha.

At the value of *L* = 100–80 %, the viability of the coenopopulation of the undergrowth is assessed as healthy, at 79–50 % the population is considered weakened, at 49–20 % it is severely weakened and less than 20 % the coenopopulation is completely destroyed.

Dataset to assess impact of surface fires on Scots pine stands

The plots were selected based on Anuchyn's field methodology (Anuchyn 1982). The classification of burned Scots pine stands was carried out according to Sofronov and Volokytyna (2007). The trees on the TSPs were counted, standard tree parameters, namely, height, diameter, sum of cross-sectional areas, wood stock, minimum and maximum scorch height on tree trunks were determined. The assessment post-fire condition of stands was carried out on a scale of tree condition categories according to 'Sanitary rules in the forests of Ukraine' (Cabinet of Ministers of Ukraine 1995). According to the rules, trees are evaluated by the shape of their crown, the presence and colour of needles in six categories: I – healthy, II – weakened, III – very weakened, IV – drying out, V – new dead wood, and VI – old dead wood. Crown defoliation was also assessed by the ICP forests method (ICP Forests 2010). The studies were carried out on 32 TSPs, out of which 18 TSPs were burned forest and 14 TSPs were unburned forest. Forestry and statistical characteristics of Scots pine stands on TSPs are given in Table 1.

Table 1. Descriptive statistics of Scots pine stands' parameters.

Taxational parameters	*n*	*M*	M_e	min	max	σ	*v*	*As*	*Es*
Burned forest									
A	18	50	49	20	125	26	51	1.46	3.14
H		18.2	18.5	6	30	6.7	37	-0.11	-0.15
DBH		16.4	15.2	5	41	8.5	52	1.43	3.40
P		0.66	0.65	0.40	0.97	0.17	26	0.26	-0.81
M		200	212	22.9	449	118	59	0.48	-0.10
Hsr_{max}		1.43	0.96	0.43	4.67	1.11	78	1.68	2.96
Hsr_{min}		1.09	0.40	0.24	4.16	1.20	110	1.97	3.99
Unburned forest									
A	14	48	37	20	125	29	59	1.60	2.83
H		17.3	16.2	6	29	7.4	43	0.14	-0.92
DBH		15.2	14.1	5	35	8.2	54	1.27	1.70
P		0.65	0.59	0.41	0.91	0.17	27	0.43	-1.27
M		184	143	23.3	391	120	65	0.53	-0.68

Note: *A* – age of the stand, years; *H* – average height, m; DBH – diameter of tree at breast height (1.3 m), cm; *P* – relative density; *M* – stock volume, m^3/ha; Hsr_{max} – maximum scorch height of the tree trunk, m; Hsr_{min} – minimum scorch height of the tree trunk, m; *n* – number of temporary sample plots; *M* – arithmetic mean; M_e – median; σ – standard deviation; *v* – variation coefficient; *As* – asymmetry coefficient; *Es* – excess coefficient.

Mathematical and statistical processing of the dataset was performed using Microsoft Excel and Statistica.

Results

Surface fires' effect on the forest ground vegetation

The analysis of the forest ground vegetation and its floristic composition 4 years after the fire in the Poliskyi Nature Reserve revealed that after a low-intensity surface fire (S_{height} < 0.5 m), the abundance and species composition of both herbs and moss layers did not change (p-value < 0.05), whereas after a surface fire of medium- (S_{height} 0.5–1.5 m) and high- (S_{height} > 1.5 m) intensity there were significant changes in the floristic composition and structure of the forest ground vegetation. After the fire, the number of plant species in post-fire TSPs increased by 49 %. 39 species were found in the burned TSPs, 37 of which were vascular plants and 2 were species of mosses, and 19 species of plants belonging to five families appeared because of the fire – Asteraceae, Polygonaceae, Onagraceae, Scrophulariaceae and Rosaceae. In particular, there was a 93 % increase in projective coverage of herbs-shrub layer and a 95 % decrease in coverage of the moss-lichen layer. The following species of vascular plants appeared in the TSPs affected by medium and high intensity fires: *Chamaerion angustifolium* L., *Erigeron canadensis* L., *Rumex acetosella* L., *Agrostis tenuis* Sibth., *Calamagrostis epigeios* (L.) Roth., *Hieracium pilosella* L., *Solidago virgaurea* L., *Gnaphalium sylvaticum* L., *Taraxacum officinale* Webb. ex Wigg., *Echinochloa crusgalli* (L.) Beauv., *Helichrysum arenarium* (L.) Moench., which are dominant. The following species of mosses, namely *Dicranum polysetum* Swartz., *Polytrichum commune* Hedw. and lichen *Cladonia rangiferina* (L.) Web. did not recover. However, new species of mosses from Polytrichaceae – *Polytrichum piliferum* Hedw. family and *Polytrichum juniperinum* Hedw. emerged.

Dominant and co-dominant species of the forest ground vegetation on post-fire TSPs are characterized by high constancy (50–67 %) and low dominance (less than 25 %). In species which constancy is equal to or exceeds 50 %, the projective coverage varies between 5–9 %. On the unburned TSPs, the forest ground vegetation species with high constancy overwhelmingly dominant, which is typical of undisturbed plant communities (Fig. 2).

The analysis of coenotic structure of forest ground vegetation in the burned and unburned phytocenoses shows that its complete regeneration occurs only after a low-intensity surface fire (p-value < 0.05). A medium-intensity surface fire decreases the participation of forest species (Sil) to 35 %, as well as the appearance of the meadow (Pr – 28 %) and invasive (Ru – 12 %) species. A high-intensity surface fire reduces the participation of forest species to 56 %, and the share of invasive species is about 19 %. Thus, the intensity of the fire is a key factor that determines the character of changes in the structure of the coenosis of the forest ground vegetation (Fig. 3).

To assess qualitative changes in species diversity in post-fire and unburned phytocoenoses, the Jaccard floristic similarity index was used. The calculations showed that after a low-intensity surface fire there is a complete species regeneration, as K_j = 1.0. On the contrary, after a

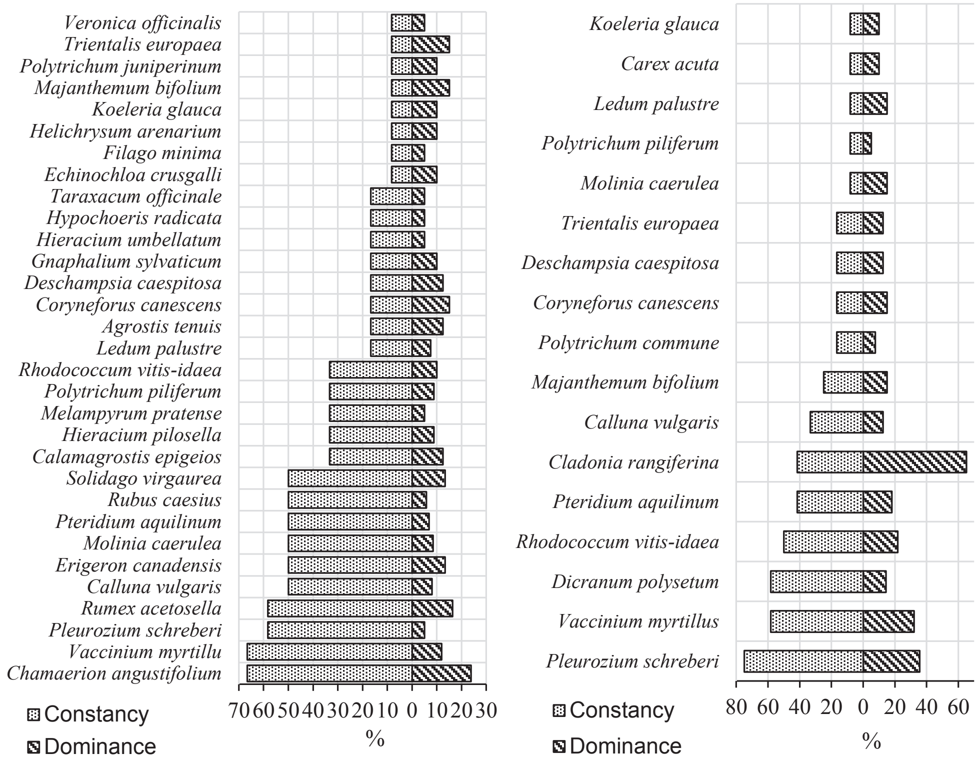

Fig. 2. Distribution of species on the burned (left) and in unburned phytocoenosis (right).

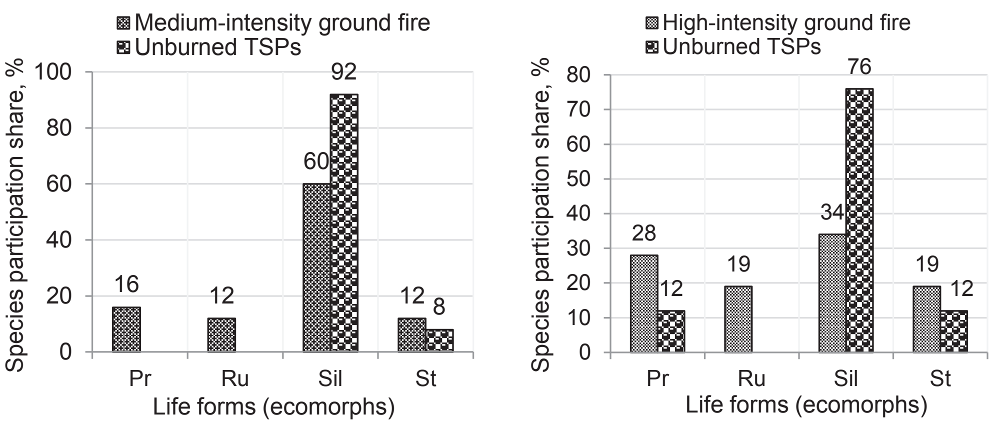

Fig. 3. Coenotic structure of forest ground vegetation after a surface fire of medium- (left) and high- (right) intensity on unburned TSPs.

fire of medium-intensity the value of the index ranged from 0.11–0.43, and after a high-intensity – 0.13–0.15. The statistical analysis of the experimental data allowed to establish a reliable inverse correlation between the floristic similarity index and the type of fire (r_s = -0.69). Thus, an increase in the intensity of the surface fire leads to a decrease in the similarity of the forest ground vegetation on TSPs between the burned and unburned plant communities.

Effect on the natural forest regeneration

The state of a post-fire forest is an important assessment factor for the success of its future natural regeneration. The study shows that after low- and medium-intensity surface fires the most successful forest regeneration occurs during the first and the second year when up to 90 % of trees' self-seeding appears. In all types of post-fire edaphic conditions satisfactory natural regeneration of pine and birch, and aspen in wet hygrotope was observed. The total amount of self-seeding and undergrowth on the burned TSPs is 78 % higher than on the unburned ones. On both TSPs, Scots pine natural regeneration is higher (80 %) compared to other tree species (Fig. 4).

The constancy of Scots pine natural regeneration on TSPs after a surface fire of medium- and high-intensity is higher than the unburned stands and ranges from 75 to 100 %. Natural pine regeneration on the burned TSPs is uniform. The deciduous tree species constancy in all types of edaphic conditions is much lower (5–32 %), and these tree species are located in small groups. Pine regeneration on the burned stands during the first two years following a fire has a marked differentiation in a tree's height. The average height of the majority (61 %) of natural regeneration is 0.26–0.5 m, which allows it to compete with herbs vegetation.

To establish the viability of Scots pine natural regeneration, classification into viability categories was carried out. Healthy one-year old pine regeneration on burned TSPs is 36 %, two-year old is 53 %, three-

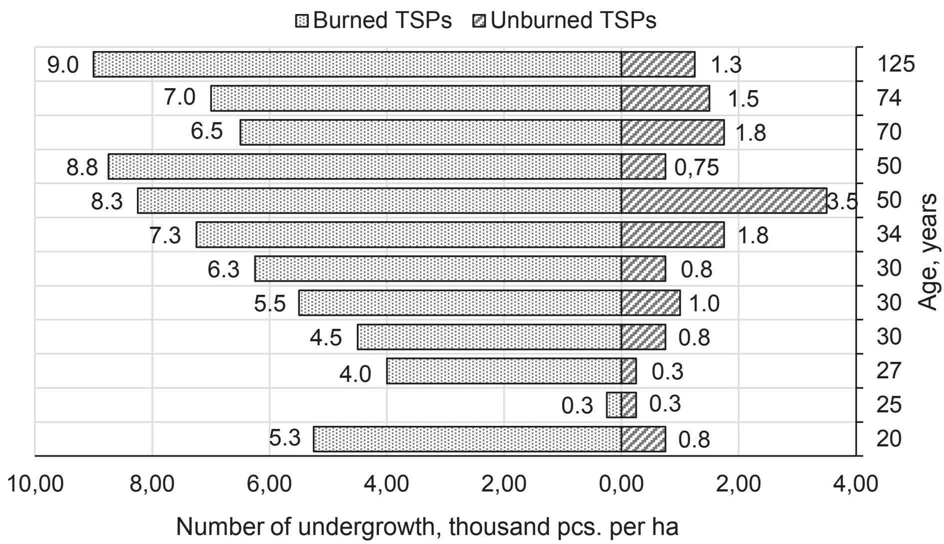

Fig. 4. Amount of Scots pine natural regeneration.

year old is 57 % and four-year old is 67 %. On the unburned TSPs, the number of healthy pine regeneration increases from the age of eight and above (81–100%). On the unburned TSPs the number of weakened pine regeneration decreases with age on starting from two years and above from 50 % to 22 %. Based on the experimental dataset statistically significant (p-value < 0.05) correlations between the viability of the natural pine regeneration and its height (r_s = 0.78), age (r_s = 0.71), and edaphic conditions (r_s = 0.68) were established.

Effect on Scots pine stands

The analysis of the collected data using descriptive statistics revealed significant variability of the obtained values in diameter (DBH), maximum (Hsr_{max}), minimum (Hsr_{min}), and average (Hsr_{avg}) scorch height on the tree trunk (Table 2). The absence of normal distribution of the studied parameters (at p-value = 0.05 or p-value for every statistic) based on Shapiro-Wilk (W) and Kolmogorov-Smirnov (λ) tests were confirmed. Therefore, it is necessary to use non-parametric statistical criteria.

Table 2. Main statistical indicators of trees in burned TSPs.

Indicators	*n*	*M*	M_e	*min*	*max*	v	*As*	*Es*
DBH	3506	15.9	14.3	1	71	63	1.28	2.47
Hsr_{max}	3477	135.5	95.0	1	650	88	1.81	3.09
Hsr_{min}	1974	106.8	43.0	1	575	122	1.69	1.90
Hsr_{avg}	1974	141.7	85.0	1	600	91	1.51	1.48
Category of tree health conditions	3506	3.1	3.0	1	6	41	0.59	-0.62
Crown defoliation, %	3506	51.7	40	5	100	60	0.50	-1.26

The nonparametric correlation analysis indicates a naturally close relationship between the category of tree health conditions and crown defoliation (r_s = 0.95) (Table 3). As the assessment of tree viability in forestry practice is carried out according to the scale of the category of tree health conditions, further studies were carried out for this indicator. There is a moderate, inverse correlation between the category of tree health conditions and the tree's diameter (r_s = −0.56). Hsr_{min} has the closest connection with the category of tree health conditions (r_s = 0.54). Thus, this indicator is better suited for predicting tree loss after surface forest fires.

Table 3. The Spearman's rank correlation coefficients between trees' indicators in burned TSPs (r_s critical is < 0.01 at p = 0.05).

Indicators	DBH	Hsr_{max}	Hsr_{min}	Hsr_{avg}	Category of tree health conditions	Crown defoliation, %
DBH	1.00	–	–	–	–	–
Hsr_{max}	**0.07**	1.00	–	–	–	–
Hsr_{min}	**-0.28**	**0.78**	1.00	–	–	–
Hsr_{avg}	**-0.16**	**0.98**	**0.88**	1.00	–	–
Category of tree health conditions	**-0.56**	**0.31**	**0.54**	**0.52**	1.00	–
Crown defoliation, %	**-0.54**	**0.34**	**0.55**	**0.52**	**0.95**	1.00

Note: here and further in the tables, statistically, significant criteria are marked in bold.

Graphical interpretation of the dependency of tree health conditions' category on the tree's diameter and the minimum scorch height allows detecting significant deviations from the approximating curves (Fig. 5). Within the first category of tree health condition, the deviations of these indicators from the trend line are significant. Therefore, mathematical dependencies have been developed to establish the distribution of trees with certain health conditions according to DBH and Hsr_{min}. The following groups of categories were distinguished: I–II – no signs of weakening, III – significant lag in growth and crown development, IV–VI – drying out, and deadwood.

Analytical dependencies of the share of trees in the selected groups of the categories of THC on their DBH and Hsr_{min} are shown in formulas (3–5).

where: p_{I-II}, p_{III}, and p_{IV-VI} are the share of trees in groups of categories of THC, %.

Power, exponential and logistic dependencies are used in the structure of formulas (3–5). Equation (4) shows the lowest percentage of oscillation of the independent variable and is characterized by the largest residuals.

Taking into account the equations 3 and 5, we created normative reference tables to estimate the percentage of trees in the selected groups of I–II and IV–VI categories of health conditions taking their DBH and Hsr_{min} as indicators. The table shows that four years after the fire for 16+ cm DBH and Hsr_{min} of 1.0 m the fall of the trees in the pine stands varies between 3–26 %. Thus, it is not critical for the further development of the stand.

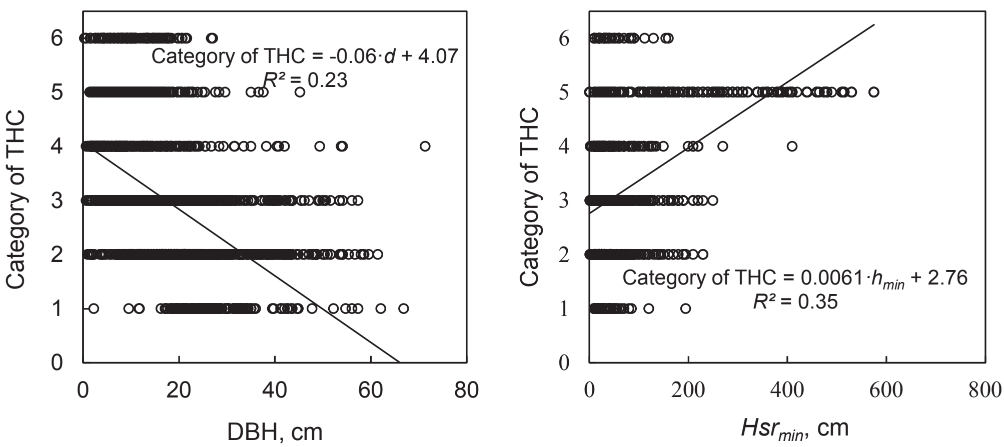

Fig. 5. Dependencies of the categories of tree health condition (THC) on DBH (left) and *Hsr*$_{min}$ (right).

$$p_{I-II} = 1.061 \cdot \left(\frac{100}{1+10^{2.12-0.124 \cdot \mathrm{DBH}}} \right) \cdot exp\left(-0.508 \cdot Hsr_{min}\right),\ R^2 = 0.78, \quad (3)$$

$$p_{III} = \mathrm{DBH}^{2.358} \cdot exp\left(-0.081 \cdot \mathrm{DBH}\right) \cdot Hsr_{min}^{2.048} \cdot exp\left(-1.648 \cdot \mathrm{DBH}\right),\ R^2 = 0.57 \quad (4)$$

$$p_{IV-VI} = 100 - 2.674 \cdot \left(\frac{100}{1+10^{1.21-0.116 \cdot \mathrm{DBH}}} \right) \cdot exp\left(-1.079 \cdot Hsr_{min}\right) \cdot Hsr_{min}^{0.683},\ R^2 = 0.74, \quad (5)$$

Discussion

Effect on the forest ground cover

The study shows that impact of forest fire on the species composition and projective cover of forest ground vegetation is determined by its type and intensity. As we expected, the moss-lichen layer in the Scots pine phytocoenosis is the most sensitive one to surface fires. In the papers of Perevoznikova (2005), Kovaleva and Ivanova (2013), a similar replacement of mosses and lichens plant associations in the post-fire pine stands of the Middle Taiga subzone is observed. In particular, after surface fires of low- and medium-intensity the moss-lichen layer experienced a decrease of species diversity, and after high-intensity fires it faced total extinction. According to the authors, high-intensity surface fires caused the appearance of micro-groups with the dominating mosses *Polytrichum piliferum* Hedw. and *Polytrichum juniperinum* Hedw. on the burned pines. Their appearance in our research was also noted, however, they are not dominant, and the micro-groups are fragmentary.

Regeneration of herbs-shrub layer species composition and structure directly depends on the fire intensity and the burning depths of forest litter. In the paper of Kovaleva and Ivanova (2013) it is noted that at the initial stage of secondary post-fire succession after medium-intensity fire there is a decrease in the projective cover of the dominant species of shrubs *Vaccinium vitis-idaea* L. and *Vaccinium myrtillus* L. and their phytomass. The authors (Ivanova et al. 2002, Perevoznykova et al. 2005) argue that high-intensity surface fires lead to the changes in the horizontal structure of the ground cover which is dominated by micro-groups with a predominance of Poaceae and Fabaceae, especially *Chamerion angustifolium* (L.) Scop. and *Calamagrostis epigejos* (L.) Roth. The results of similar studies in Belarus (Parfenov et al. 1985) show that after surface fires of medium- and high-intensity in a burned pine forest with relatively poor transitional soils more abundant and diverse species composition of the live ground cover is formed. This paper also notes that in pine stands on extremely poor soils the process of herbs' regeneration takes decades and goes through a series of successive stages, which are characterized by the predominance of different species of Poaceae, mosses, and lichens. Despite the fact that the abovementioned study areas are situated in different locations, it should be noted that they are still in the same climatic zone (temperate), and the course of post-fire successions of the forest ground cover is similar to our data for Northern Ukraine.

Effect on the natural forest regeneration

A set of favourable conditions is important for the regeneration of natural Scots pines after forest fires (Buzykyn and Popova 1978, Usenia 2000). The emergence and continuity of natural pine regeneration depends on surface fire intensity, combustion of the forest floor layer (Furiaev et al. 2005, Perevoznykova et al. 2005), age, edaphic conditions, seed availability, seed years (Kalynyn 2002, Hille 2006, Meng et al. 2015), and the suppression of herbs-shrub vegetation (Ivanova et al. 2002).

In this paper, similar dependencies are observed, in particular, it was found out that 4 years after the surface fires on TSPs with significant (45–100 %) combustion of the forest floor layer there is a successful (7.7–9.5 thousand pcs. per ha) natural pine regeneration. It was established that these years were not seed ones. The scale of natural Scots pine regeneration on the unburned TSPs can be described as unsatisfactory, which is 0.25–1.75 thousand pcs. per ha. During four years after the surface fire there is a significant competition of natural regeneration with the plant species of forest ground cover. Thus, the competition is a determining factor in the formation structure of natural Scots pine stands.

Also in the post-fire TSPs, natural pine regeneration depends on stand age and edaphic conditions. The scale of natural pine regeneration on the burned TSPs reliably (*p*-value = 0.05) depends on the average age of the forest. In the stands aged 50–70 years, the highest number of pine regenerations (7.7–9.5 thousand pcs. per ha) was observed after low- (S_{height} < 0.5) and medium- (S_{height} 0.5–1.5 m) intensity surface fires. Likewise, the viability of Scots pine seedlings on the burned TSPs depends on edaphic conditions. The share of healthy trees of the natural regeneration increases with the improvement of soil fertility and wetness from A_{1-2} (47–52 %) and B_{2-3} (65–81 %), except for A_4. Significant moisture and the fact that the soil is completely covered with green mosses of Sphagnaceae and Polytrichaceae make the emergence of the seedlings in this edaphic condition impossible. Only on burned TSPs with damp and extremely wet soils natural regeneration of aspen (*Populus tremula* L.) and birch (*Betula pendula* Roth.) was observed. Natural oak (*Quercus robur* L.) regeneration was observed only on the unburned TSPs (0.5–0.8 thousand pcs. per ha). Thus, edaphic conditions affect the peculiarities of natural Scots pine regeneration after surface fires.

Effect on the Scots pine stands

In the study, we confirmed the statistically significant (*p*-value = 0.05) relationship between the categories of tree health conditions with the Hsr_{min} and DBH, which allowed us to develop mathematical dependencies, and on their basis to create normative reference tables to estimate tree losses after surface fires (Table 4).

Table 4. Prediction of tree losses share (IV–VI categories), %.

DBH,	Hsr_{min}, m										
cm	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
4	85.2	86.2	89.4	92.5	94.9	–	–	–	–	–	–
8	66.7	68.8	76.0	83.0	88.4	92.4	–	–	–	–	–
12	41.4	45.2	57.8	70.1	79.7	86.6	91.3	94.4	96.5	97.8	98.6
16	20.8	25.9	43.0	59.5	72.5	81.9	88.2	92.5	95.3	–	–
20	9.9	15.6	35.1	54.0	68.7	79.4	86.6	–	–	–	–
24	5.4	11.5	31.9	51.7	67.2	78.3	–	–	–	–	–
28	3.8	9.9	30.7	50.8	66.6	–	–	–	–	–	–
32	3.2	9.4	30.3	50.5	–	–	–	–	–	–	–
36	3.0	9.2	30.2	–	–	–	–	–	–	–	–
40	2.9	9.1	–	–	–	–	–	–	–	–	–
44	2.9	9.1	–	–	–	–	–	–	–	–	–
48	2.9	9.1	–	–	–	–	–	–	–	–	–
52	2.9	–	–	–	–	–	–	–	–	–	–
56	2.9	–	–	–	–	–	–	–	–	–	–
60	2.9	–	–	–	–	–	–	–	–	–	–

At Hsr_{min} up to 1.0 m and DBH ≥ 28 cm, the percentage of drying trees is similar to the one possessing no signs of drying, i.e. low-intensity surface fire have a negligible impact on the pine stands. Similar results were obtained in the researches in Northern Ukraine (Voron et al. 2017) and South Belarus (Usenia 2000).

In the paper of Usenia (2000), the prediction of tree losses share is underestimated by 42–68 %. This is explained by the author in a mathematical model in which the average stand values are used as a DBH, height scorch, and tree losses share, which is characterized by greater variability and lower accuracy. In our study, forecasting is based on the values of each tree in the pine stand. Comparing the results of our research with the abovementioned ones, we can state that the dynamics of the categories in the burned forest can vary, which complicates the prediction of post-fire effects. Thus, the study of the effects of varying intensity surface fires on Scots pine stands has great practical and economic importance and requires further research.

Conclusions

Wildfires remain a constant and significant environmental factor influencing the formation and development of Scots pine forests in the Poliskyi nature reserve. The reaction of forest ground cover to the surface fire is manifested differently and can be represented by both small short-term changes, and the degradation and elimination of plant communities, which results in the emergence of secondary ecological successions. In particular, low-intensity surface fires (S_{height} < 0.5 m) do not change the species composition, the projective cover, and the coenotic structure of the forest ground cover. At the same time the surface fires of increased intensity cause succession in the herbs-shrub and moss-lichen tiers with typical forest species being replaced by invasive ones. Therefore, the duration and the character of secondary ecological successions and the recovery of the unburned phytocoenosis directly depend on the type and intensity of the surface fire.

Surface fires are stimulating the emergence and development of the natural Scots pine regeneration. Natural regeneration in a burned forest is 78–81 % higher than in an unburned one. The most successful natural regeneration occurs during the first two years after a low- and medium-intensity surface fire in medium stand density with the trees aged 50–70. The undergrowth of aspen and birch is scarcely represented, whereas Scots pines prevail. Low competition of seedlings with the herbs cover during the first year after the fire helps to preserve more natural pine regeneration. The share of healthy pine regeneration grows from 36 to 67 % with the increased age and height of the regeneration.

Low- and medium-intensity surface fires do not cause losses or critical changes to the structure of pine stands with an average DBH ≥ 16 cm. In general, these types of surface fire do not cause statistical differences in the distribution of trees by DBH in both burned and unburned forest. The representatives of Environmental Resources Management may in some cases anticipate the use of the positive role of surface fires in the fire management system. Thus, the study of surface fire effects on the components of forest ecosystems is relevant and requires further research.

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