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Trends in forest fuel accumulation in pine forests of Kyiv Polissya in Ukraine

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Abstract

At present, forest fire research is becoming especially relevant in Ukraine. This study examines patterns of forest fuel accumulation in pine (*Pinus sylvestris* L.) stands that grow in different soil conditions with different pine stand structure. To estimate the load of forest fuel of different fractions, a combined methodology was used: the weighing method and the FIREMON (fuel load estimation) method.

It was found that increase in surface forest fuel loads is not directly proportional to forest stands' age. Fractional size distribution, capacity and loads of forest fuel depend on several factors, among which the greatest role is played by forestry characteristics of the pine stand. It was determined that in the forest site conditions of type C (fairly rich soils) in Kyiv Polissya, the share of forest litter compared to pine stands that grow in poor soil conditions (A) is smaller, ranging from 41% to 76% of the total forest fuel load. The mass proportion of the duff layer varies from 15% in young forest stands to 43% in mature stands. It was established that changes in forest fuel fractions for 1, 10, 100 and 1000 hours varied insignificantly with age rate. The share of substratum woody debris of 10 and 100 hours was insignificant and depended more on the forestry treatment regime on these sites. The mass proportion of coarse woody debris (1000 hours) was also insignificant, varying from 0% to 5.9% of the total load of surface fuel.

Key words

Pinus sylvestris L., pine stands, forest fires, litter, forest fuel

Introduction

At present, forest fire research is becoming especially relevant in Ukraine. Fire behaviour modelling is based on the data of the quantitative and qualitative characteristics of forest fuel, relief and climatic conditions. In Ukraine, research on forest fuel (FF) is fragmentary (various forest conditions, using different methods, etc.). Researching the characteristics, properties and peculiarities of mortmass formation and accumu-

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lation of forest litter as well as other surface forest fuels will allow to predict its ability to ignite, fire behaviour and potential post-fire risks for damaged forests (Sydorenko et al. 2021). Currently, several groups of Ukraine's scientists are actively working on the study of forest fuels and on elaborating harmonized methods for their assessment. In pure pine forests, litter and duff are the main and the most flammable fuel (Levchenko et al. 2015). The most important qualitative characteristics that affect fire intensity during forest litter burning are its moisture content, density (specific gravity) (Kurbatsky 1970), load, ratio between mineralization layers and fractional composition (Sofronov and Volokitina 2007). The Laboratory of Forest Pyrology NULES of Ukraine(Hurzhii and Yavorovsky 2018; Zibtsev et al. 2018) has started developing a comprehensive landscape fire geoportal for the Ukrainian Polissya forests in order to model fires' behaviour, to give a preliminary assessment of fire consequences and to determine natural fire hazards. One of the main sets of input data for this portal is relevant information on FF reserves in specific homogeneous forest areas. Forest fuel research in Ukraine is conducted by Drach et al. (2017), Zibtsev et al. (2018), Voron et al. (2018a, 2018b), Yavorovsky et al. (2018, 2019), Sydorenko (2018) and Hurzhii and Yavorovsky (2018). The aim of this study is to determine the main trends in forest surface fuel accumulation in pine forests of Kyiv Polissya.

Material and methods

The research was conducted within the framework of Kyiv Polissya. During sample plots laying, we carried out the description of forest areas in accordance with generally accepted methods of forest taxation (Svyrydenko 2007) and methodologies for fuel assessment elaborated by Kurbatsky (1974), Sofronov and Volokitina (2007). During the taxation description of the plots, stand composition and its age were determined. On the basis of trees listing, the average height, diameter and plantations density were determined. Forest canopy closure was identified; underwood, undergrowth and forest live cover (FLC) were described; species composition and projective cover for FLC were also determined (Svyrydenko 2007); the soil and its mechanical composition were described (Svyrydenko 2007).

As is well known, a number of factors influence surface FF load: stand forestry indices, forest growth conditions (soil types, etc.), forest health indicators (sanitary condition), relief and climatic factors. All forest sites in Ukraine are classified by soil moisture and soil nutrient status (Pohrebniak 1959; Ostapenko and Tkach 2002). The soil moisture scale comprises six classes (hygrotopes) from 0 to 5: 0, very dry; 1, dry; 2, fresh; 3, moist; 4, wet; and 5, very wet. The soil nutrient status includes four classes (trophotopes): A, poor (*bir*); B, fairly poor (*subir*); C, fairly rich (*sugrud*); D, rich (*grud*). Site conditions are formed by combining a trophotope with a hygrotope (e.g. A_1 – *dry bir*). Sample plots were laid in conditions of A_2, B_2 and C_2. Proceeding from this, the study was carried out of FF mass loads and fractional composition in different variants of forest growth conditions according to soil-hydrological features (A_2, B_2 and C_2).

When collecting research data, alongside M.P. Kurbatsky's and M.A. Sofronov's methods, the FIREMON (Lutes et al. 2006) technique was used. Forest litter loads were determined in the forest stands. For this purpose, discount areas (1 m^2 rectangle) have been laid. The raking of litter was carried out after the termination of its formation in July–August, prior to needle cast. If the litter did not have distinct layers, it was collected on a sample plot in its entirety. But if it had distinct layers, each layer was collected and weighed separately after drying it out till it reached air-dry condition.

On the sample plots (Kurbatsky 1970), before sampling, the height (thickness) of FF layers was measured, then the grass and bushes were cut as well as self-seeding and undergrowth, which in height did not exceed the height of the grass-bushy layer. After that, litter, leaf debris, mosses and lichens were collected by cutting the litter along the plot's lines with a sharp knife. The selected samples were packed in plastic bags, and their mass was determined under field conditions. Then they were dried in a thermostat within 24 hours to a completely dry mass at a temperature of 100–105°C. Forest fuel was divided into two groups. Group 1 included moss and litter (combustion conductors by the classification of Volokitina) (Sofronov and Volokitina 2007). Enzymatic (F) and decomposed horizon (H) (F and H horizons together form the duff layer) belonged to group 2. The mass of surface fuel, as a rule, did not exceed 3 kg per m^2. The average mass of forest litter from all discount areas was counted again on 1 ha (Kurbatsky 1974; Sofronov and Volokitina 2007; Svyrydenko 2007).

According to this technique, transects of 20 metres long were laid on areas for forest fuel measurement. There the estimation of the mass of different fractions of forest litter, litter thickness, canopy density of the forest stand and the average height of living and dead ground cover was performed. Also, for large wood residues, their distribution by destruction classes was carried out. Fractionation was done according to the US Classification of surface fuels, which does not take into account very fine particles. According to this technique, two large categories of fuel were identified: dead and live. In its turn, dead fuel is divided into four groups depending on their drying speed (time lag): light (1-hour time lag fuel), medium (10-hour time lag fuel), heavy (100-hour time lag fuel) and very heavy (1000-hour time lag fuel) (Pyne et al. 1996). The smallest particles (1 hour $d < 0.6$ cm and 10 hours $d = 0.6–2.54$ cm) were estimated on the length of a 2-metre segment; 100-hour ($d = 2.54–7.62$ cm) particles were estimated on the length of a 5-metre segment; and 1000-hour ($d > 7.62$ cm) particles were estimated along the total transect length, each group being recorded separately with indication of its status. The thickness, the ratio between the layers of the forest litter and forest live cover recording were determined on circular areas at elevations of 10- and 20-metre transects. Four transects were laid on each forest site. A cord of an appropriate length was used with marks of 2.5 and 10 metres for recording the fractions. Only those particles that intersected the transects were counted. The data collected in this way were processed using the FIREMON methodology (Lutes et al. 2006).

The correlation analysis, the regression analysis and one-way ANOVA were performed alongside general methods (Atramentova and Utevskaya 2007).

Table 1. Load of surface fuel in pine forests of Kyiv Polissya

C_2						
100% Scots pine	15	1.17	60	13.8	0.0	0.0
95% Scots pine + 5% European oak	15	0.80	64	9.2	0.3	0.8
100% Scots pine	30	1.30	165	19.9	5	0.0
95% Scots pine + 5% European oak	45	0.72	249	22.7	9.4	3.0
100% Scots pine	60	0.71	314	37.4	4.2	3.1
95% Scots pine + 3% European oak + 2% European hornbeam	80	0.71	370	16.8	3.5	5.1
B_2						
95% Scots pine + 3% European oak + 2% Norway maple	15	0.89	54	8.9	0.2	0.8
96% Scots pine + 4% European oak	15	0.88	43	7.9	0.2	0.7
95% Scots pine + 2% European oak + 2% European birch + 1% Aspen	23	0.92	99	21.3	3.4	0.1
96% Scots pine + 4% European birch	43	0.74	173	29.7	3.8	0.8
96% Scots pine + 4% European birch	50	0.67	274	11.9	4.2	2.7
95% Scots pine + 5% Elm	60	0.72	314	29.0	4.2	4.0
100% Scots pine	70	0.80	273	28.7	4.7	3.2
A_2						
100% Scots pine	75	0.74	370	45.4	7.9	4.0
100% Scots pine	80	0.83	299	37.7	7.9	4.7
96% Scots pine + 4% European birch	85	0.79	306	23.4	4.2	0.8
100% Scots pine	90	0.65	313	46.0	4.2	5.4

*DWD, dead woody debris.

Results

It was established that the increase in the load of surface forest fuel with the advance of the stand age was not uniform (Tab. 1), especially in the conditions of *fresh subors* (B_2). The reason for this is forestry characteristics inhomogeneity of each forest stand. The trend of surface fuel load increase with stand age occurs due to the growth and development of trees in the stand, when the supply of needles in the crowns increases and the rate of decomposition slows down. Fractional composition and reserves of forest fuel depend on a number of factors, among which the greatest role is played by silvicultural and taxation (forestry) characteristics of each forest stand.

Fractional structure of forest fuel

In pinewoods that grow on sites with poor nutrient conditions where sandy soils (A_2) prevail, litter and duff comprise the main portion of surface forest fuel. Their share is more than 81% of the total surface forest fuel load (Fig. 1).

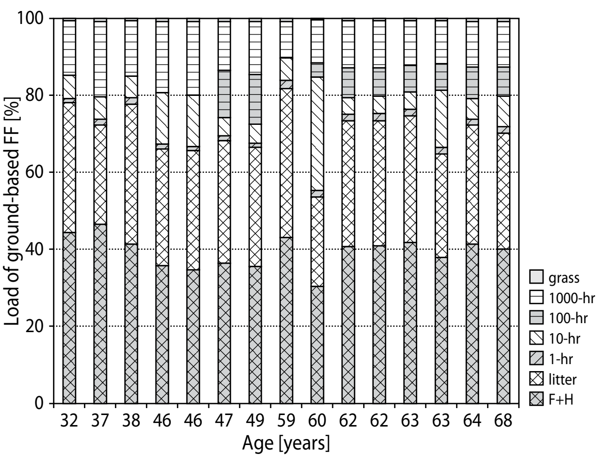

Figure 1. Fractional composition of surface forest fuel in pure pine forests, growing in forest site conditions of *fresh bir* (A_2).

The portion of enzymatic and humified layers varies from 30.4% (10.1 t·ha^{-1} at the age of 60) to 46.5% (14.9 t·ha^{-1} at the age of 37) and that of litter from 23.3% (7.8 t·ha^{-1} at the age of 60) to 38.8% (11.52 t·ha^{-1} at the age of 59). The part of small twigs (fine woody debris – 1 hour) and live surface cover (grasses and mosses) is insignificant, rarely reaching 2.1% (0.61 t·ha^{-1} at the age of 59) and 1% (0.29 t·ha^{-1} at the age of 37) of the total fuel amount. The share of 10-hour fine woody debris (FWD) ranges from 4.4% (1.2 t·ha^{-1} at the age of 62) to 29.4% (9.8 t·ha^{-1} at the age of 60) and increases with deterioration of the sanitary condition of pine stands. The load of 100-hour FWD is practically absent in the stands of age classes III–V; its significant increase can be observed when pine trees reach the age of more than 47 years, when its share in the total volume of FF increases to 3.6% (1.2 t·ha^{-1} at the age of 60) and to 12.9% (5.42 t·ha^{-1} at the age of 42). Coarse woody debris (CWD) 1000 hours comprises 9.6% (2.8 t·ha^{-1} at the age of 59) and 19.6% (6.3 t·ha^{-1} at the age of 37) of surface forest fuels.

In pine woods growing in fairly poor conditions (B_2), the share of litter is bigger by 10%, reaching over 91% of the total load of surface FF (in the young pine stands) (Fig. 2).

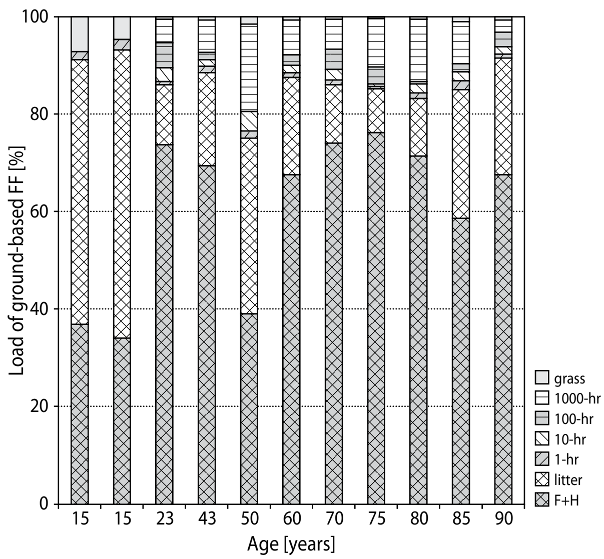

Figure 2. Fractional composition of surface FF in pure pine stands growing in the conditions of *fresh subir* (B_2)

The share of enzymatic and humified layers (duff) is significantly higher than that in the condition type A_2 and varies within 34.1% (2.9 t·ha^{-1} at the age of 15) and 76.3% (41.4 t·ha^{-1} at the age of 75). There is a clear increase in the proportion of humified and enzymatic layers with age. The share of the litter layer varies within a significant range from 8.9% (4.8 t·ha^{-1} at the age of 75) to 59.1% (5.1 t·ha^{-1} at the age of 15), having high values in pine forests of age class II (11–20 years) and decreasing with the age of pine stand. The share of FWD (1 hour) is insignificant, rarely reaching 2% (0.2 t·ha^{-1} at the age of 15), while live surface cover reaches 7% (0.7 t·ha^{-1} of the total amount of forest fuel for the same age). The share of 10-hour FWD is also insignificant, up to 4% (0.7 t·ha^{-1} at the age of 50) (which is 25.4% less in comparison with pine forests). The load of 100-hour forest fuel is practically absent in pine stands of age class II. Its significant increase is observed after the pines reach the age of more than 20 years, when its share in the total amount of FF increases to 5% (1.3 t·ha^{-1}). CWD (1000 hours) ranges from 2.4% (1.3 t·ha^{-1}) to 18% (3.2 t·ha^{-1}) of surface FF. However, there is no clear correlation ($p \leq 0.05$) with changes in stand age; probably, it is more dependent on the specific forestry activities on these sites.

Under conditions of C_2, the share of forest litter, in comparison with pine woods that grow in poorer soil conditions B_2, is insignificant, varying within 41%–76% of the total FF load (Fig. 3).

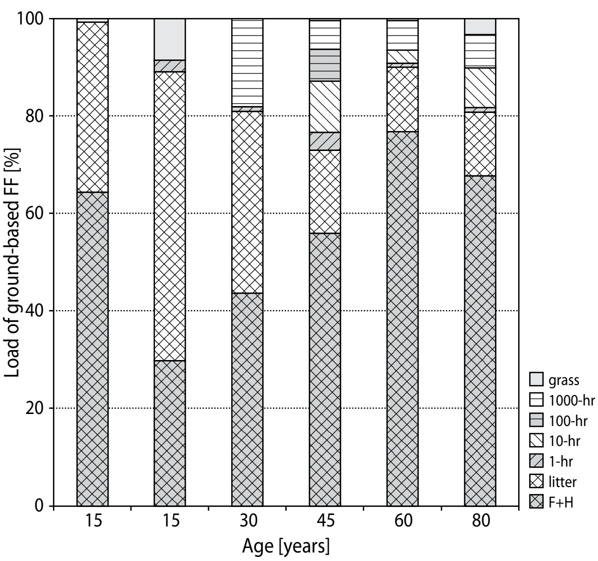

Figure 3. Fractional composition of surface FF in pure pine woods growing in conditions of *fresh sugrud* (C_2)

The share of enzymatic and humified layers ranges from 29% (3.1 t·ha^{-1} in 15-year-old young stands) to 76.8% (33.7 t·ha^{-1} in ripening 60-year-old forest stands). There is a clear increase in particle mass of the humified and enzymatic layers with the age of the stands. The particle mass of the litter layer is the largest in young growths, amounting to 59.3% (6.3 t·ha^{-1}). The particle mass of the smallest FWD (1 hour) ranges from 0.8% (0.2 t·ha^{-1} at 80 years of age) to 3.6% (1.3 t·ha^{-1} at the stand age of 45). The load of FWD 10 hours amounts to 10.5% (3.7 t·ha^{-1} at 45 years of age). The load of larger FWD 100 hours is practically insignificant in the pine stands up to 30 years of age. The particle mass of CWD (1000 hours) comprises up to 18.1% (4.7 t·ha^{-1}) of the surface FF, which is due to timely silvicultural activities.

Load of surface forest fuel

Irregular increase in forest litter load with the age of pine stands was established. Thus, in the stands of age class II, it constitutes 8.4–11.5 t·ha^{-1}, reaching a maximum in the stands of age classes V–VII (14.4–41.5 t·ha^{-1}). Such a significant variation in the indicators is explained by differences in the rate of litter accumulation and decomposition under conditions of various trophotopes (Tab. 2).

In B_2 condition, the maximum mass of litter load is reached in middle-aged pine stands (37.5 t·ha^{-1}), and then, at the age of 71–80, it decreases to 16.8 t·ha^{-1}. In C_2 condition, the maximum mass of forest litter accumulates in stands up to age class VII (41.5 t·ha^{-1}). Conversely, under conditions of *fresh bir* (A_2), litter loads vary with age within insignificant limits: 14.8–17.4 t·ha^{-1}.

In the forest growth conditions of *fresh sugrud* (C_2) in pine stands of age class V, FWD load is the largest (13.4 t·ha^{-1}); later on, it gradually decreases as the age class of stands increases. In *fresh sugrud* (C_2) conditions, the fallen timber mass load is larger in age class VII stands (7.9 t·ha^{-1}). At the same time, in the conditions of *fresh sugrud* (C_2), the largest load of CWD was found in age class IV plantations (9.4 t·ha^{-1}).

The thickest litter layer was recorded in age class III pine stands, growing in conditions of *fresh sugrud* (C_2). Its load reaches 8.46 t·ha^{-1}. In the conditions of *fresh subir* (B_2) in age class IX pine stands, it reaches 7.58 t·ha^{-1}. At the same time, in age class VI plantations in the conditions of *fresh bir* (A_2), the largest load of litter was only 3 t·ha^{-1}.

In forest growing conditions of *fresh sugrud* (C_2), fractions of FWD 100 and 10 hours have the largest load mass in age class IV stands (2.3 t·ha^{-1} and 3.7 t·ha^{-1}). At the same time, the fraction 1 hour has the largest load mass in age class VII, while its smallest load was recorded in age class II (0.1 t·ha^{-1}). In forest type condition B_2, the fraction 100 hours has a large load in age

Table 2. Forest fuel load by fractions in various types of forest conditions (TFC) and age groups, t·ha^{-1}

Age class	Litter (needle fall)	Duff	Litter and duff	DWD by fractions*				Total surface fuel
				1 hour	10 hours	100 hours	1000 hours	
C_2								
II	5.5		6.1	0.1			0.2	11.8
III	14.5		11.4	5.0			5.0	29.9
IV	8.0		19.6	3.4	3.7	2.3	9.4	41.5
V	8.4		33.7	1.5	1.2		4.2	44.3
VII	4.4		14.8	1.7	1.8		3.5	23.8
B_2								
II	5.2		3.3	0.2			0.2	8.8
III	4.4		18.9	1.4	0.7	1.3	3.4	28.1
IV								0.0
V	9.3		15.8	3.2	0.6	0.3	4.0	28.9
VI	7.9		24.9	2.7	0.7	1.1	4.4	37.8
VII	11.1		38.0	6.2	0.6	1.1	7.9	57.3
IX	12.4		27.1	2.4	0.7	1.1	4.2	43.1
A_2								
IV	13.5		12.3	4.9	1.6		6.6	27.9
V	19.4		14.7	7.1	3.7	2.6	13.4	44.2
VI	12.9		11.5	3.9	5.8	0.6	10.2	34.9
VII	12.5		11.8	3.9	2.0	2.2	8.1	30.6

*DWD, dead woody debris.

class III (1.30 t·ha^{-1}) and the smallest in age class V (0.3 t·ha^{-1}). Fraction 10 hours has a considerable mass load in age class III (0.71 t·ha^{-1}); the largest load of fraction 1 hour was identified in age class VII and the smallest one was identified in age class II of forest stands (0.2 t·ha^{-1}). In forest growing conditions of *fresh bir* (A_2), fraction 100-hour largest load was found in age class V plantations (2.60 t·ha^{-1}) and the smallest one was found in age class VI plantations (0.60 t·ha^{-1}). Fraction 10 hours has the largest load in age class VI forest stands (5.76 t·ha^{-1}) and the smallest one in age class IV (1.62 t·ha^{-1}). At the same time, fraction 1 hour has the largest load in age class V plantations (7.1 t·ha^{-1}) and the smallest load in forest stands of age classes VI and VII (3.9 t·ha^{-1}).

Changes in the levels of soil nutrient status, stand age and sanitary state of the pine stands affect the fractional composition and the total supply of surface FF. With soil fertility increasing, the load of surface FF is growing. This is caused, first of all, by the increase in the surface FF load and forest live cover with forest stands age. With pine stand age increasing, the fractional structure of surface FF grows; the load of FF in age class II increases, and the share of needles, bark and twigs mass (FWD) decreases.

It was determined that increase in surface FF loads with advancing age of the forest stand takes place unevenly, especially in *fresh subir* conditions (B_2). The reason for this is the forestry indicators heterogeneity of each stand. The load of FF increasing with age occurs due to the pine stand's above-ground fitomass accumulation, enhancement of needles load in crowns and deceleration of FF decomposition speed. The latter is explained by a change in the reaction of the soil environment through the gradual acidification of the soil mantle by needles' litter, which occurs annually. The increase in the acidity level of the soil mantle leads to the decreased activity of soil micro- and mesofauna. Fractional composition, power and mass loads of FF depend on a number of factors, among which forestry characteristics of the pine stand have the greatest significance.

It was established that with the forest stand age and soil trophicity level increasing, the fractional composition changes, and FF load grows ($r = 0.4$, $p = 0.05$).

Changes in forest litter loads with the forest stand age increasing occur unevenly, especially in *sugrud* C_2, where the largest load mass was observed at the age of 50, amounting to 39.52 t·ha^{-1}. The smallest one was observed at the age of 75 (8.08 t·ha^{-1}). The stands that grow in conditions of *fresh sugrud* at the age of 15 in the logged areas and open glades displayed differences. Forest litter mass load in the logged area appeared larger and was 13.82 t·ha^{-1}, and in the open glade, it was 9.41 t·ha^{-1}.

Forest litter mass load of pinewoods growing in conditions of *fresh sugrud* C_2 is the largest in 80-year-old forest stands (49.83 t·ha^{-1}) and the smallest one in 60-year-old stands (25.36 t·ha^{-1}). Forest litter mass load in 15-year-old stands in the logged areas was 31.30 t·ha^{-1}, while in open glades, it was 29.75 t·ha^{-1}.

In pine forest stands growing in forest type of *fresh bir* A_2, the largest mass load of forest litter was observed in 38-year-old forest stands (34.80 t·ha^{-1}) and the smallest one was observed in 32-year-old plantations (17.87 t·ha^{-1}).

Forest litter specific gravity

It was determined that forest litter specific gravity varies from 15.2 to 115 g·dm³ and depends on the pine stand relative density. For the plantations of 0.65–1.30 relative densities, average data on litter specific gravity for different age groups were obtained experimentally (Fig. 4).

Litter specific gravity in forest growth condition C_2 ranged from 19.4 to 115.2; in condition B_2, from 34.3 to 88.8; and in condition A_2, from 15.2 to 49.8 g·dm³. This indicates that the density level of the litter layer increases with the soil fertility. A clear tendency for the forest conditions B_2 and A_2 to change specific gravity of forest litter with the pine stand's age was revealed. Specific gravity of forest litter is also dependent on the relative stand density ($r = 0.5$; $p = 0.05$). For the conditions of *fresh subir* B_2, there is a maximum litter density in middle-aged stands (68.5 g·dm³) and a sharp decline in specific gravity in mature plantings up to 20.9 g·dm³ due to rapid forest litter decomposition under pine stands.

In the course of the correlation analysis, a direct reliable correlation between litter specific gravity increase and the relative density growth was identified ($r = 0.6$; $p = 0.05$).

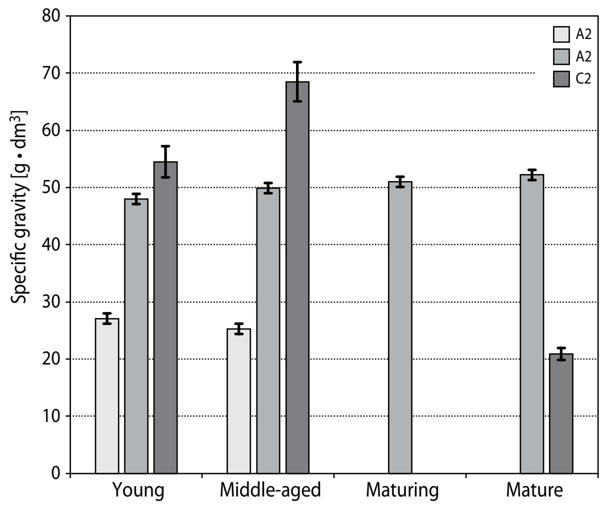

Figure 4. Characteristics of forest litter specific gravity depending on pine stand age and type of forest growth conditions.

Canopy fuel

The largest needles load in pine stands growing in conditions of *fresh subir* (B_2) was identified in 85-year-old forest stands (5.93 t·ha^{-1}), and the smallest one was identified in 23-year-old plantations (2.39 t·ha^{-1}). In pine plantations growing in conditions of C_2, the highest load mass index was recorded in 30-year-old plantations (8.46 t·ha^{-1}) and the smallest one was recorded in 80-year-old forest stands (2.09 t·ha^{-1}). In pinewoods that grow in A_2 conditions, the largest needles load mass was recorded in 59-year-old forest stands (3.70 t·ha^{-1}) and the smallest one was recorded in 32-year-old plantations (1.62 t·ha^{-1}).

Discussion

The studies by numerous scientists have shown that significant forest fuel loads are concentrated in forest ecosystems, especially in coniferous stands, and this is a determining factor of forest fire hazards emergence. It should be emphasized that most publications contain data on FF quantity, yet are confined to data on forest litter and organic leaf fall only. In Prof. V.V. Usenia's opinion, for determining FF loads in forest stands, this is not sufficient since living ground cover (such as grasses) should be taken into account in equal measure. These features were taken into account in his research while estimating surface FF quantity in the stands of coniferous species of woody plants in the Republic of Belarus (Usenia and Churylo 2001). We believe that it is necessary to consider the study of FF quantity not separately but in combination with the climate of natural zones because litter and living ground cover, if viewed separately, will not give a clear understanding of fuel accumulation and the reasons affecting causes of forest fires hazard. This is why our research was conducted within Kyiv Polissya, and in the future, the research will be conducted in other natural climatic zones of Ukraine. Besides, as distinct from N.P. Kurbatsky (1970) and a number of scientists, who believe that forest growth conditions type does not significantly affect forest litter thickness in the context of a particular forest type, we found that the litter loads depend on trophic conditions. Litter volume is lower in *sugrud* conditions (C_2), where litter decomposition processes are more intensive (Hurzhii and Yavorovsky 2018).

It should be noted that the influence on coarse (CWD) and fine woody debris (FWD) by fractions is primarily connected with different forestry indicators of stands and different climatic conditions (Zibtsev et al. 2018). A similar trend has been identified also for litter and duff load in pine forests (Sydorenko 2018).

The analysis of needles load mass in pinewoods has shown that with the advance of stands age, its growth is not uniform, namely, in conditions of *fresh subir* (B_2) at the age of 15, the load reaches 5.2 $t{\cdot}ha^{-1}$, while at the age of 23, it reaches 2.4 $t{\cdot}ha^{-1}$. In the conditions of *fresh sugrud* (C_2) at the age of 30, it amounts to 8.5 $t{\cdot}ha^{-1}$, while at the age of 80, it amounts to 2.1 $t{\cdot}ha^{-1}$. In the conditions of *fresh bir* (A_2) at the age of 59, the load reaches 3.7 $t{\cdot}ha^{-1}$, while at the age of 63, it reaches 2.1 $t{\cdot}ha^{-1}$.

Needles (litter layer) load increment with the stands age occurs due to needle mass growth in crowns and decrease of its decomposition rate as a result of changing soil mantle reaction through its acidification by needle fall.

The total loads of forest litter and duff also increase unevenly; however, according to S.H. Sydorenko (2018), litter loads under *subir* (B_2) conditions in the Left-Bank Forest-Steppe pine forests increase evenly with age, reaching a peak at the age of 70–80 years (60 $t{\cdot}ha^{-1}$), and for the conditions of Western Polissya, it reaches up to 80.3 $t{\cdot}ha^{-1}$, which is exclusively related to the climatic features of the research regions (Voron et al. 2018b).

It was found that forest litter specific gravity in forest vegetation condition C_2 ranged from 19.4 to 115.2; in condition B_2, from 34.5 to 88.8; in condition A_2, from 15.2 to 49.8 $g{\cdot}dm^3$, which indicates that with increasing the trophic conditions of soils the level of litter layer density increases.

Similar conclusions were drawn by S.H. Sydorenko in his work: in *fresh subir* (B_2) conditions of Left-Bank Forest Steppe (Eastern part of Ukraine), litter specific gravity varies from 51 (in low-density plantations and young stands) to 141 $g{\cdot}dm^3$, depending on stand density, age and ratio between the scarification layers of litter and duff (Sydorenko 2018). According to Voron's data, for the *moist sugrud* C_2 in Western Polissya (Northern Ukraine) forest litter density (specific gravity) depended on stand age, ranging from 30.6 to 97.3 $g{\cdot}dm^3$ (Voron et al. 2018a).

For the conditions of *fresh sugrud* C_2, there is a maximum increase in litter density in medium-age stands (68.5 $g{\cdot}dm^3$) and a sharp decline in terms of specific gravity in mature pine stands to 20.9 $g{\cdot}dm^3$. This is explained by rapid forest litter decomposition under forest stands with admixture of deciduous tree species and a decrease in relative density of pinewoods with age.

Conclusions

It was shown that fuel load of 100-hour time lag fuel, 10-hour time lag fuel and fine woody debris (1-hour time lag fuel) depend mainly on stand productivity indicators (age, average diameter and relative density). Forest litter layer load is directly proportional to relative density of pine stands and does not depend on stands age. Conversely, the load of the duff layer increases with the stands age, being directly proportional to the average diameter, height and stand stock and inversely proportional to relative density. It was shown that with increasing the soil nutrient status of forest growth conditions, starting with the conditions of *fresh sugrud* C_2, FWD and CWD loads decrease rapidly.

References

Atramentova L.O., Utevska O.M. 2007. Group comparison and relations analysis (in Ukrainian). Ranok Publishing House, Kharkiv, Ukraine.

Drach K.L., Tovarianskyi, V.I., Kuzyk A.D. 2017 Investigation of litter fire hazard in the pine young stands under weather conditions (in Ukrainian). 19th Ukrainian scientific-practical conference 'Current state of civil defense of Ukraine and prospects for development' Kyiv, Ukraine 105–113.

Hurzhii, R.V, Yavorovsky, P.P. 2018. The surface forest fuels load in the forests of Kyiv Polissya.Ukraine (in Ukrainian). *Forestry and Forest Melioration*, 132, 124–130. DOI: 10.33220/1026-3365.132.2018.124

Kurbatsky N.P. 1970. Investigations of quantity and properties of forest combustible materials (in Russian). In: Problems of Forest Pyrology. Institute of Forests and Timber, Krasnoyarsk, Russia, 3–58.

Kurbatsky, N.P. 1974. Problems of Forest Pyrology (in Russian). Siberian Branch of the Academy of Sciences of the USSR, Krasnoyarsk, Russia.

Levchenko, V.V., Borsuk, O.A., Borsuk, A.A. 2015. Forest fuel: study guide (in Ukrainian). NULES of Ukraine, Kyiv, Ukraine.

Lutes, D.C. et al. 2006. FIREMON: Fire effects monitoring and inventory system. Gen. Tech. Rep. RMRS-GTR-164. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. DOI: 10.2737/RMRS-GTR-164

Ostapenko, B.F., Tkach, V.P. 2002. Forest typology (in Ukrainian). Kharkiv State Agrarian University, Kharkiv, Ukraine.

Pohrebniak, P.S. 1959. Fundamentals of forest typology. Publishing house of the Academy of Sciences of the USSR, Kyiv, Ukraine

Pyne, S.J., Andrews, P.L., Laven, R.D. 1996. Introduction to Wildland Fire. Second Edition. John Wiley and Sons, New York, USA.

Svyrydenko, V.Ye. 2007. Silviculture. Lectures (in Ukrainian). Aristei, Kyiv, Ukraine.

Sofronov, M.A., Volokitina, A.V. 2007. Methodology of pyrological examination and descriptions of forest areas passed by fires. V.N. Sukachev Institute of Forest SB RAS, Krasnoyarsk, Russia.

Sydorenko, S., Voron, V., Koval, I., Sydorenko, S., Rumiancev, M., Hurzhii, R. 2021. Postfire tree mortality and fire resistance patterns in pine forests of Ukraine. *Central European Forestry Journal*, 67, 21–29. DOI: 10.2478/forj-2020-0029

Sydorenko, S.H. 2018. The estimation of litter mortmass as the basic fire fuel of pinewood forests in the left-bank forest-steppe (in Ukrainian with English summary). *Forestry and landscape gardening*, 14. Available at http://journals.nubip.edu.ua/index.php/Lis/article/view/12601 (access 11 May 2021).

Usenia, V.V., Churylo, V.S. 2001. The dynamics of postfire mortality in pine stands (In Russian). *Problems of Forest and Forestry: collection of scientific works of Institute of Wood of NAS of Belarus*, 52, 209–214.

Voron, V.P., Sydorenko, S.H., Tkach, O.M. 2018a. Structure of forest litter as an indicator of potential fire risk in the pine forests of Polissya, Ukraine (in Ukrainian). *Forestry and Forest Melioration*, 132, 115–123. DOI: 10.33220/1026-3365.132.2018.115

Voron, V.P., Tkach, O.M., Sydorenko, S.H., Melnyk, Ye.Ye. 2018b. Stock of forest litter and ground vegetation as an indicator of fire risk in the pine forests of Polissya (in Ukrainian). *Proceedings of the Forestry Academy of sciences of Ukraine*, 16, 9–16. DOI: 10.15421/411801

Yavorovsky, P.P., Hurzhii, R. V., Sydorenko, S. H. 2018. Forest fuel in pine stands of Boyarka forest research station as a key factor of fire hazard level in the forest. In: Proceedings of International scientific-practical conference 'Development problems of forest taxation, forest management and forests inventory', 6–8 December 2018, NULES of Ukraine, Kyiv, Ukraine, 134–135.

Yavorovsky, P.P., Hurzhii, R.V., Sydorenko, S.H. 2019. Formation of the complex of ground forest combustible materials in pine forests of Kyiv Polissya (in Ukrainian). *Ukrainian Journal of Forest and Wood Science*, 10 (2), 73–81. DOI: 10.31548/forest 2019.02.072

Zibtsev, S.V., Lakyda, P.I., Borsuk, O.A., Yavorovsky, P.P., Humenuk, V.H., Koren, V.A. 2018. Fire hazard of Chernobyl exclusion zone forests and their fire resistance increasing. Mohography. Kyiv, Ukraine.