



Polycyclic aromatic hydrocarbons in post-fire soils of drained peatlands in western Meshchera (Moscow region, Russia)

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Abstract. Polycyclic aromatic hydrocarbons (PAHs) are priority pollutants that arrive in the environment from numerous anthropogenic and natural sources, but the data on their natural sources including wildfires remain insufficient. The level of contamination and the composition of PAHs in soils of the areas affected by wildfires were studied in this work. The study was conducted in the Moscow region (Russia) in areas occupied by drained peatland and strongly damaged by fires in 2002, 2010 and 2012. The features of PAH accumulation and the profile distributions in histosols and histic podzols after the fires of different times were analyzed. It was shown that new soil horizons formed after the fires – C_{pir}, H_{pir} and incipient O horizons – and that these horizons differ in PAH accumulation rate. Maximal total concentrations of 14 PAHs were detected in charred peat horizons H_{pir} (up to 330 ng g⁻¹) and in post-fire incipient O horizons (up to 180 ng g⁻¹), but the high-molecular-weight PAHs (benz(ghi)perylene, benz(a)pyrene, benz(k)fluoranthene) were revealed only in charry peat horizons. The trends of higher PAH concentrations were found in cases when smoldering combustion resulted in rather thick residual peat horizons. In cases of almost complete pyrogenic destruction of He horizons, total PAH concentrations were no more than 50 ng g⁻¹. Also, PAH accumulation in upper horizons of soils near the sites of the latest fires was observed.

1 Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a group of high molecular weight organic compounds, which include carcinogens and mutagens. PAHs are formed in natural and technogenic processes, and are ubiquitous in different landscape components. Scientific interest in PAHs has remained high during recent decades (Wilcke, 2000; Haritash and Kaushik, 2009; Cai et al., 2008; Gennadiev et al., 1996; Bandowe et al., 2014; Maisto et al., 2006; Baek et al., 1991). Most PAHs in the environment arrive from pyrogenic sources. So far, pyrogenic anthropogenic sources of PAHs (automobile exhaust, various industrial and power plant emissions) are well studied (Khan et al., 2008; Mastral and Callen, 2000; Tsibart and Gennadiev, 2013; Wilcke, 2000, 2007; Agarwal, 2009; Kwon, 2014; Mu et al., 2013) and, nowadays, in developed countries, there is a trend of reducing environmental contamination with PAHs because of improvement in technologies (Guo et al., 2011).

The number of PAHs arriving in the environment from natural pyrogenic sources (wildfires, volcanism) remains uncertain. Numerous works are devoted to PAH formation from vegetation components influenced by flaming and smoldering combustion. Burning conditions (the amount of available oxygen, the duration of heating, the temperature) and the type of vegetation define the amount and composition of PAHs (Ramdahl and Bechler, 1982; Jenkins, 1996; Nussbaumer, 2003; Medeiros and Simoneit, 2008; Simoneit, 1999; Schauer et al., 2001; Nakajima et al., 2007; Fitzpatrick et al., 2008; Kakareka et al., 2004).

The publications devoted to pyrogenic PAHs in the territories affected by wildfires do not cover the range of questions related to this problem. For instance, the peculiarities of PAH composition in the air after a wildfire were studied in several works (Radojevic, 2003; Masclet et al., 1995; Maioli et al., 2009; Freeman and Cattell, 1990; Yuan et al., 2008), but there is an obvious lack of information on pyrogenic PAH accumulation in soils. Some publications are focused on PAHs in different organo-mineral soils that were subjected to fire (Gennadiev and Tsibart, 2013; Dymov et al., 2014; Gonzalez-Vila et al., 1991; Garcia-Falcoan et al., 2006; Vergnoux et al., 2011). It was shown that PAHs accumulated in these soils in small amounts and posed no danger to humans. However, PAH accumulation in soils after smoldering fires causing deep changes in soil profiles was investigated insufficiently (Vane et al., 2013; Gennadiev and Tsibart, 2013; Bojakowska and Sokołowska, 2003).

Peat fires differ from other fire types, because the burning material in this case is not only the vegetation, but also the soil organic matter. The conditions present in peat smoldering favor PAH formation because fires propagate slowly and deep soil horizons are affected by high temperature (Rein et al., 2008; Hartford and Frandsen, 1992). Moreover, in comparison to flaming fires, smoldering consumes most of the peat. Also, smoldering drives the spread of the pyrolysis front where PAHs are produced, and the smoldering process occurs under conditions of low oxygen and temperature (500–700 °C) compared with flaming fire (Rein, 2013). These conditions favor the processes of organic radical recombination and PAH formation.

It is worth noting that the combustion products differ depending on the peat type, moisture and the completeness of combustion. Products of pyrolysis are a gaseous mixture of organic species released into the air. They include volatile organic compounds, hydrocarbons (CH₄, C₃H₈, CH₃OH) and particulate matter. During the oxidation stage of combustion, CO and CO₂ are produced (Rein, 2013). Peat smoke also contains sulfur, potassium, oxides of nitrogen (Blake et al., 2009) and metals (Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Ti, V, Zn) (Betha et al., 2013). PAHs are part of the peat combustion products in most cases and, after the fires, they generally accumulate across the whole soil profile (Vane et al., 2013; Kakareka et al., 2004; Blake et al., 2009). So, PAHs can accumulate in situ in char and ash layers before they are released into the atmosphere (Rein, 2013). Moreover, below the fire front, higher production of aromatic and condensed molecules takes place (Zaccone et al., 2014), and gaseous PAHs after releasing into the atmosphere can also be transported and accumulate at other sites (Rein, 2013).

In most cases, the scientific literature contains data on pyrogenic PAHs in undrained peat soils. The drained soils, following fire, are not studied from this context, although they are very vulnerable to wildfires (Blake et al., 2009; Zaidel'man et al., 2007). Large amounts of organic matter burn out during the fires, and deep transformations occur in

the profiles, in comparison with the soils of undrained territories (Zaidel'man et al., 2007, 1999). The drained peat soils are widespread in densely populated areas of the European part of Russia, and an important task is to reveal levels of accumulation of PAHs in these areas.

The aim of this study was to reveal the features of PAH accumulation in podzols and histosols of drained peatlands affected by wildfires. Study objectives included (1) the comparison of PAH distributions and levels of accumulation in different post-fire soils, histosols and podzols, (2) the identification of the parts of post-fire soil profiles with maximal PAH accumulation, (3) the detection of the trends of different PAH group accumulation, and (4) the comparison of PAH accumulation in soils after fires of different times.

2 Materials and methods

2.1 Study area

This study was conducted in the soils of Shatura district (Moscow region, Russia). The burned area is located at coordinates 55°39' N, 39°36' E with an elevation of 120 m. The investigated site is situated 15 km to the north of Shatura (Fig. 1) and 200 m to the west of the village of Dolgusha (Fig. 2).

The territory represents the western Meshchera fluvio-glacial plain. The major part of the area is covered by fluvial–glacial deposits, although alluvial deposits also occur. The elevation is within the limits of 120–126 m, and the relief is low (Wetlands of Moscow Region, 2008; Zonov and Konstantinovich, 1932).

The investigated area is covered with peatlands overlying ancient alluvial deposits, which are located above the confining clay layer. The development of these wetlands is caused by a flattened relief and a shallow horizon of waterproof clay. The area covered with peat bogs in this part of the Meshchera plain is 15–16 % (Wetlands of Moscow Region, 2008; Zonov and Konstantinovich, 1932; Kudravtseva, 1973).

The investigated plot belongs to the Petrovsko–Kobelevskoe high-moor peat, which is a part of the Shatura wetland area. Its total area is 6443 ha; before the era of peat extraction, the thickness of the peat layer reached 7.5 m, and its average thickness was 2.5–4 m (Zonov and Konstantinovich, 1932).

These large areas were transformed during the drainage and peat mining. Beginning at the end of the eighteenth century, the peat bogs of the Moscow region were used as peat fields. The demand for peat increased in the 1920s, when peat-burning power stations including Shaturskaya station were constructed (Wetlands of Moscow Region, 2008; Simakin, 1958). The peat deposits in the Shatura district were mined beginning in the 1920s (Timashev, 1932). Now mining no longer occurs, and most of the peat bogs in Meshchera

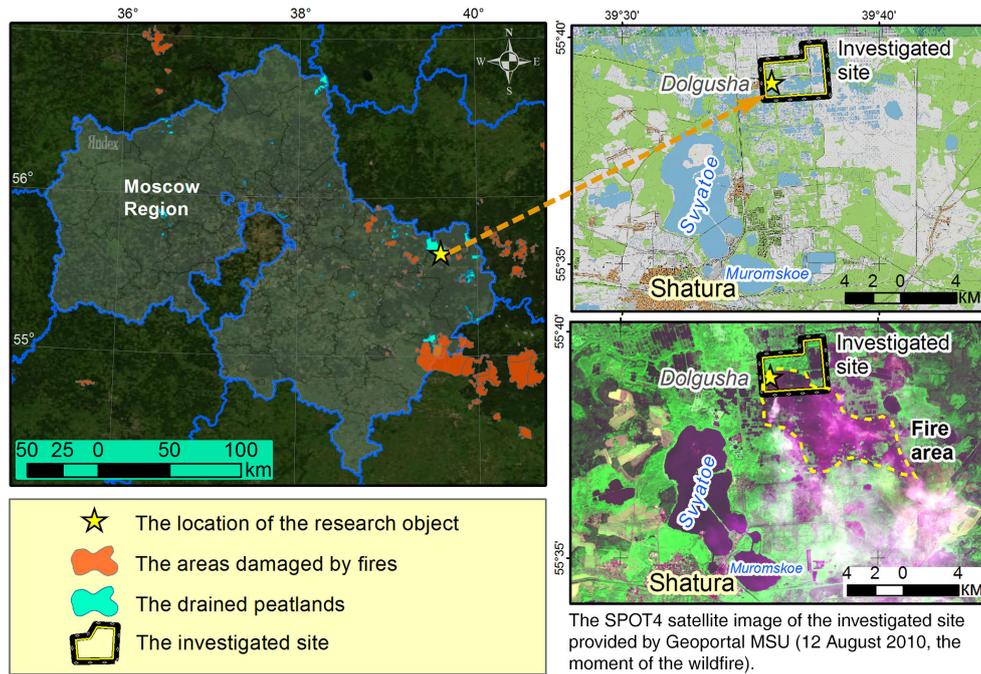


Figure 1. The location of the research site.

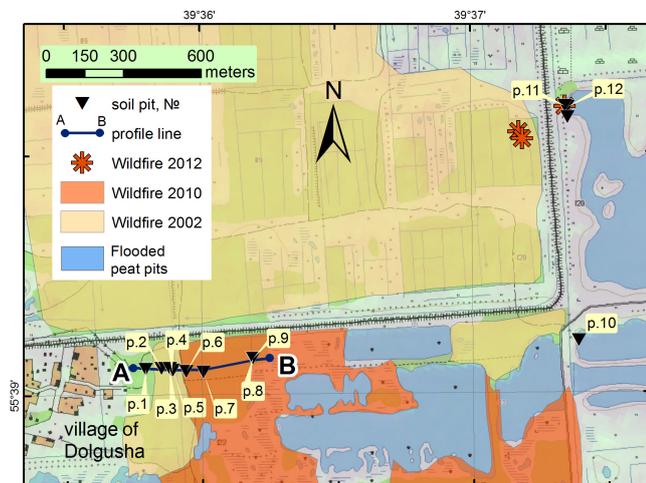


Figure 2. The location of the investigated soil pits.

bog province are in a stage of recovery (Wetlands of Moscow Region, 2008).

As a result of peat mining, natural bog complexes were changed to large open pits connected to systems of channels and distributaries and to fields of peat mining at different stages of recovery, with birch–aspen forests occurring on their banks. On the plots with flooded peat pits, the process of bog restoration has started, but it will take several centuries before peat deposits will start to accumulate (Sushkova, 2008).

Because of changes in hydrological regime, the number of areas of peat fires has increased dramatically in this region (Wetlands of Moscow Region, 2008). According to Zaidel’man (2003), there is a repeating pattern of the fires in drained peatlands. Almost every 10 years, large fires occur (1972, 1982, 1992, 2002). In 2010, wildfires in Russia damaged large areas and, in the Moscow region, they caused significant air pollution, degradation of ecosystems and health impacts for the population (Donkelaar et al., 2011; Shvidenko et al., 2011).

The soil cover of the area is presented by gleyic histosols, histic podzols and sod podzols (WRB, 2006) variously altered by the wildfires. Podzols are formed under forest vegetation on sandy parent material in terms of water percolation. These soils have an eluvio-illuvial distribution of organo-mineral complexes within the profile. Histosols are characterized by the accumulation of organic matter and various compounds in thick peat horizons, and they contain more material available for burning. One important goal of our study was to establish the patterns of PAH accumulation in different soil types and to check if post-fire PAH distribution follows general soil-forming processes.

Background soils are represented by histosols and histic podzols. The histosols have the following horizons, O–H–Hp–He–Ha–C, and a typical profile of histic podzols has O–A–E–EBhs–Bhs–Cs horizons. After the smoldering fire and burning out of the peat layer, the new ash horizons (Cpir) up to 5 cm in depth form; they are underlain by peat *cherry horizons* (Hpir) with 2–3 cm and *pyrogenic muck peat horizons* (Ha,pir) with 2–3 cm in thickness.

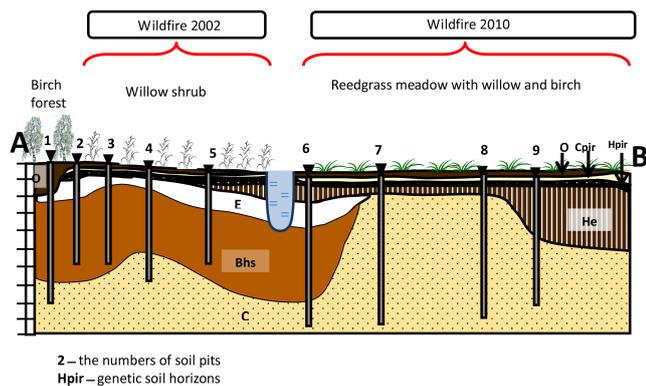


Figure 3. The profile characteristics of the investigated soils.

Post-pyrogenic histic podzols are confined to the peripheral part of peatlands; the parent material for them is bare quartz sands, and typically their profile has the following horizons: O–Cpir–Hpir–He–Ha–E–EBhs–Bhs–Bh–BC–C. Post-pyrogenic gleyic histosols occupy large areas and form in the central parts of peatlands; their profile consists of O–Cpir–Hpir–He–Ha–Ch–Cs–Cg (Figs. 3, 4).

It should be pointed out that the thickness of horizons in soils affected by the fire varies, depending on the intensity of the pyrogenic impact. The depth of organogenic horizons in soil pits ranges from 10 to 30 cm at a distance of several meters.

2.2 Soil sampling and laboratory analysis

In order to study PAH accumulation in post-fire soils of different types, the areas covered with histosols (pits 7, 8, 9, 11, 12) and sod podzols (pits 2, 3, 4, 5, 6) were sampled, as well as areas with analogous background soils (pits 1, 10) (Fig. 3).

For the comparison of PAH accumulation in soils after fires of different times, the areas affected by the fires of 2002, 2010 and 2012 were studied. The field work and sampling were conducted in 2012 and, in total, we studied 12 soil pits (Fig. 2).

Soil pits were excavated to a depth of 50–100 cm, depending on the depth of the parent material. Detailed morphological descriptions of soil profiles were made.

For the identification of the parts of post-fire soil profiles with maximal PAH accumulation, the samples were collected from each genetic horizon and, in cases of thick horizons (more than 10 cm), samples were taken at 10 cm intervals. Samples were stored in plastic bags and taken to the laboratory, where they were air dried, homogenized and sieved through a 0.25 mm sieve.

The target PAHs in this study were naphthalene, pheanthrene, chrysene, pyrene, anthracene, benz(a)anthracene, benz(a)pyrene, benz(ghi)perylene, fluorene, dibenzthiophene, triphenylene, benz(e)pyrene, benz(k)fluorantene, and

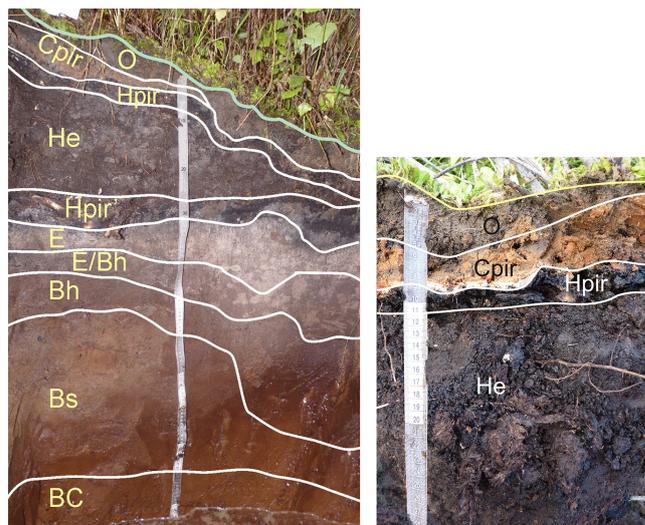


Figure 4. Soil profiles investigated. 1-post-pyrogenic histic podzol (pit 6), 2-post-pyrogenic histosol (pit 8).

coronene. This group of compounds includes PAHs from low-molecular-weight to high-molecular-weight compounds (2–7 benzene rings in their structure), which are widespread in the environment.

The quantitative analysis was conducted with the spectrofluorometry method at the temperature of liquid nitrogen (Spolskii spectroscopy) (Alexeeva and Teplitskaya, 1988; Gooijer et al., 2000; Personov, 1981; Gennadiev et al., 1996).

Liquid extraction was used in the analysis. 3 g of air-dried soil samples were extracted with *n* hexane (5 mL) at room temperature. The degree of extraction was controlled by the absence of extract luminescence under UV light. In cases of the presence of extract luminescence, the extraction was continued with 5 mL of *n* hexane. This method of extraction excluded an alteration of matter, as is possible by thermal or acoustic effects and other kinds of intensive extractions.

The measurements were done on a Jobin Yvon Fluorolog-3-22 spectrofluorimeter. The extract was frozen in liquid nitrogen (77 K). Then, the mixture of PAHs in the frozen extract was irradiated by light with optimum wavelengths for each compound, and the PAH luminescence spectra were recorded (Fig. 5).

The wavelengths of the excitation and emissions of luminescence used for the PAH identifications are given in Table 1. Spectral fractionation (identification of each hydrocarbon by the most optimum excitation and luminescence wavelengths) was used. High selectivity of the method is obtained by using a spectra selection of PAHs in multicomponent solutions by scanning the narrow excitation wave band (Alexeeva and Teplitskaya, 1981). Identification and quantitative estimations of PAHs were made by comparison of fluorescence and excitation spectra with the SRM NIST 2250a (36 PAHs mixture) reference standard solution. Limits of

Table 1. The wavelengths of the excitation and emissions of luminescence used for the PAH identifications.

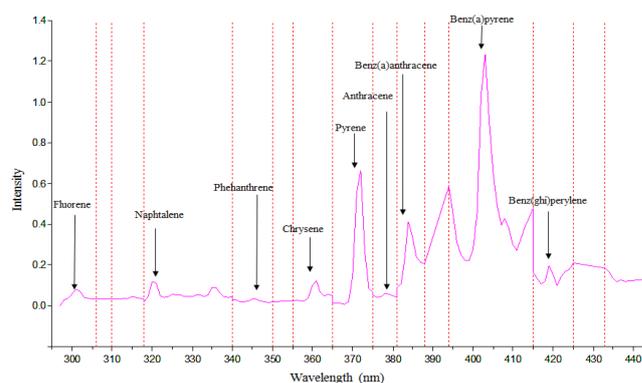
PAH	Excitation (λ , nm)	Emission (λ , nm)
Naphthalene	290	322
Phenanthrene	293	346
Chrysene	269	361
Pyrene	352	372
Anthracene	253	378
Benz(a)anthracene	290	384
Benz(a)pyrene	367	402
Benz(ghi)perylene	367	419
Fluorene	288	302
Dibenzophenone	286	425
Triphenylene	287	462
Benz(e)pyrene	333	388
Benz(k)fluoranthene	310	401
Coronene	300	445

detection (LOD) for each PAH were $\leq 0.1 \text{ ng g}^{-1}$. The limits of quantification (LOQ) for each PAH were $\leq 0.5 \text{ ng g}^{-1}$. In total, 109 soil samples were analyzed for PAH concentration. The analysis was done in one replicate.

2.3 Statistical analyses

The results were analyzed with STATISTICA 8.0. The distribution of total PAHs in each horizon type was tested for normality with the Kolmogorov–Smirnov test, and each group included similar horizons from a similar soil type, so sample replicates were considered; the number of values in each group was from 6 to 14. The data did not follow the normal distribution at significance level $p > 0.05$. So, a nonparametric Kruskal–Wallis ANOVA test was conducted for comparison of the PAH concentrations in different horizons. This test does not require the normal distribution. The differences in PAH concentrations in different horizon types were represented in categorized boxes and whisker plots. The Kruskal–Wallis ANOVA test was also used for the statistical estimate of differences between soils affected by wildfires of different years. The upper horizons of the soils were considered in this test. All statistical tests were performed at the standard significance level $p < 0.05$.

Cluster analysis was conducted to find similarities in the distributions of the individual PAH compounds. In this analysis, complete linkage was used as the amalgamation rule, and the distance metric was 1-Pearson r . PAHs were combined in clusters if the coefficient of correlation in every group was significant at $p < 0.05$. Moreover, for each compound, the coefficient of variation was calculated.

**Figure 5.** PAH luminescence spectra for SRM NIST 2250a.

3 Results

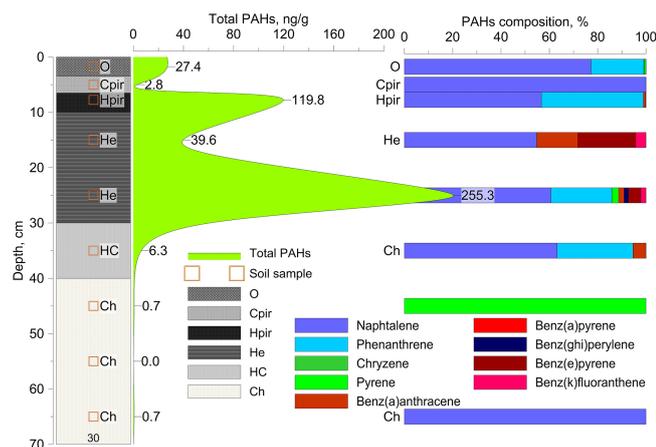
The studied soils varied highly in PAH concentrations; their total content changed from 5 to 330 ng g^{-1} . In the histosols not affected by fire (pit 10), the total PAH concentrations ranged from 19.6 to 137.2 ng g^{-1} within the profile; their composition included naphthalene, benz(a)anthracene and phenanthrene. In the histic podzols not affected by fire (pit 1), the total PAH concentration varied from 35.4 ng g^{-1} in horizon A to 0.2 ng g^{-1} in horizon BC. Naphthalene and pyrene prevailed in this profile. In mineral horizon Bhs, only naphthalene and, sporadically, pyrene occurred. Phenanthrene and benz(a)anthracene were found only in organic horizons (Table 2).

3.1 Profile distributions of PAHs in soils of different types

The common features of PAH distribution in *post-fire histosols* (pits 7, 8, 9) were the following (Fig. 6, 7, Table 3). These soils had the ash horizon Cpir at depth 2–5 cm, and typically at these sites they had low PAH concentrations ($5\text{--}8 \text{ ng g}^{-1}$). Below and above the Cpir horizon, there were two maxima of PAH concentration. The first maximum of PAH concentration was detected in surface incipient horizon O ($20\text{--}70 \text{ ng g}^{-1}$), where mainly 2-3-nuclear compounds (naphthalene, phenanthrene, anthracene) occurred. The second maximum was below Cpir in pyrogenic charry peat horizons (Hpir). In these horizons, the total PAH concentration reached 255 ng g^{-1} . The PAH composition in these horizons was also different. Cpir horizons had predominantly low-molecular-weight compounds: 2-nuclear naphthalene and 4-nuclear pyrene. In Hpir horizons, 5-6-nuclear compounds prevailed: benz(ghi)perylene, benz(e)pyrene, benz(k)fluoranthene and naphthalene occurred in lower concentrations. In underlying organic horizons, He and Ha benz(a)anthracene occurred. In humic-infiltrated horizon Ch, low PAH concentrations (up to $5\text{--}10 \text{ ng g}^{-1}$, coefficient of variation for total PAHs 106 %) were registered, and hydrocarbons were represented only by naphthalene.

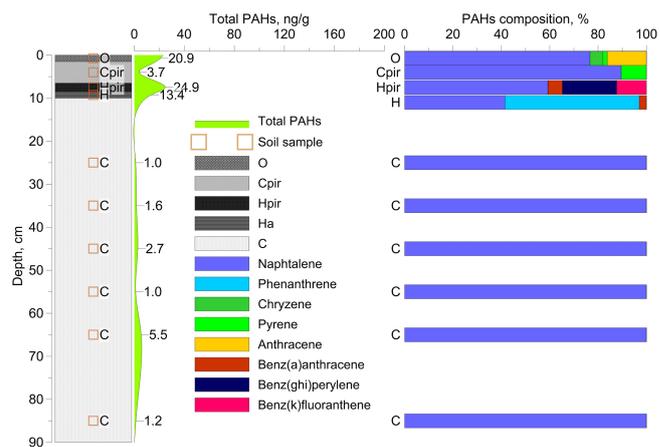
Table 2. PAH concentrations (ng g^{-1}) in soils of unburned area.

Horizon depth, cm	Horizon	Naphthalene	Phenanthrene	Chrysene	Pyrene	Anthracene	Benz(a)anthracene	Benz(e)pyrene	Benz(ghi)perylene	Fluorene	Dibenzofluorene	Perylene	Triphenylene	Benz(e)pyrene	Benz(k)fluoranthene	Coronene	Total PAHs
Histosol (pit 10)																	
0–5	He	11.0	<LOD	<LOD	<LOD	<LOD	8.6	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	19.6
5–10	He	29.1	36.1	<LOD	<LOD	3.4	11.6	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	80.2
10–15	He	40.6	49.3	<LOD	<LOD	<LOD	19.7	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	109.6
15–20	He	34.7	38.0	<LOD	<LOD	<LOD	9.6	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	82.3
20–30	Ha	32.5	<LOD	<LOD	<LOD	<LOD	16.2	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	48.7
30–40	Ha	45.9	<LOD	<LOD	<LOD	<LOD	12.0	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	57.9
40–50	Ha	63.5	27.2	<LOD	<LOD	<LOD	46.5	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	137.2
Histic podzol (pit 1)																	
0–1	O	8.7	26.7	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	35.4
1–10	A	2.7	6.3	<LOD	<LOD	0.3	0.9	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	10.2
10–18(21)	A	6.9	11.8	<LOD	<LOD	<LOD	12.1	<LOD	<LOD	<LOD	<LOD	0.1	<LOD	<LOD	1.3	<LOD	32.3
18(21)–26	E	3.3	2.3	<LOD	<LOD	<LOD	0.1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	5.6
26–37(40)	E/Bhs	5.3	<LOD	<LOD	0.1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	5.4
37(40)–55(57)	Bhs	3.0	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	3.0
55(57)–65	Cs	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.2	<LOD	<LOD	<LOD	<LOD	0.2

**Figure 6.** The profile distribution and composition of PAHs in post-fire histosol in the case of a thick organogenic horizon (pit 9).

Post-fire histosols had various differences in PAH distribution. In pit 9, the thicknesses of undestroyed peat horizons were greatest among the investigated soils (approximately 30 cm), and PAH concentrations were also highest in this case – up to 255 ng g^{-1} ; moreover, PAH concentrations were relatively high within the entire depth of the organic layer. PAH composition was represented by a wide range of compounds – from low-molecular-weight to 5-6-nuclear compounds – benz(ghi)perylene, benz(e)pyrene and benz(k)fluoranthene. In cases of more complete combustion of peat (pits 8 and 7) where mineral material was present from 10 to 14 cm in depth, the total PAH concentrations were much lower – from 5 to 25 ng g^{-1} (Fig. 7).

It may be noted that total PAH concentrations in residual peat horizons of post-fire histosols changed from 10 to 255 ng g^{-1} , with coefficients of variation in the He horizon of

**Figure 7.** The profile distribution and composition of PAHs in post-fire histosol in the case of almost complete burning out of the organic layer (pit 8).

118 and 155 %. At sites with more complete combustion of peat, PAH molecules accumulated in smaller amounts ($10\text{--}20 \text{ ng g}^{-1}$). In cases of incomplete burning, their concentrations in peat horizons were greater than 200 ng g^{-1} .

The Kruskal–Wallis ANOVA test indicated significant differences in total PAH concentrations between different horizon types of histosols. Significant differences were detected between mineral C and post-fire Hpir horizons, and between mineral C and organogenic H horizons at $p < 0.05$. In addition, mineral horizons (Ch, Cs, C) had the smallest ranges and mean values, and organogenic horizons (Hpir, He, Ha) had the greatest ranges and mean values (Fig. 8).

Sod podzols and histic podzols (pits 4, 5, 2, 3, and 6) subjected to wildfires were slightly different in levels of PAH accumulation. Also, there were two maxima of total

Table 3. PAH concentrations (ng g^{-1}) in post-fire soils.

Horizon depth, cm	Horizon	Naphthalene	Phenanthrene	Chrysene	Pyrene	Anthracene	Benz(a)anthracene	Benz(a)pyrene	Benz(ghi)perylene	Fluorene	Dibenzofluorene	Perylene	Triphenylene	Benz(e)pyrene	Benz(k)fluoranthene	Coronene	Total PAHs
Histosol (Pit 11)																	
0–0.5	O	55.5	19.4	<LOD	1.1	0.3	<LOD	<LOD	<LOD	<LOD	0.1	<LOD	<LOD	<LOD	<LOD	<LOD	76.5
0.5–2(4)	Cpir	8.3	<LOD	<LOD	0.1	0.1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	8.5
2(4)–7	Hpir	0.9	0.6	<LOD	<LOD	<LOD	0.1	<LOD	2.6	<LOD	<LOD	<LOD	<LOD	2.4	<LOD	0.2	6.7
7–8	He	1.4	0.4	<LOD	<LOD	<LOD	0.3	<LOD	3.8	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	5.9
8–14	He	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.3	0.3
14–26	Ch	1.2	<LOD	<LOD	0.2	<LOD	0.1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	1.5
26–38	Cs	1.2	1.5	<LOD	0.2	<LOD	6.5	<LOD	<LOD	<LOD	0.2	<LOD	<LOD	<LOD	<LOD	<LOD	9.7
38–50	Cs	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.0
50–60	C	1.8	<LOD	<LOD	0.2	<LOD	0.1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	2.1
60–70	C	1.0	<LOD	<LOD	0.2	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	1.2
70–80	C	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.0
80–90	C	0.5	<LOD	<LOD	0.2	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.7
Sod podzol (pit 5)																	
0–2(3)	O	9.4	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.3	<LOD	<LOD	<LOD	<LOD	<LOD	9.7
2(3)–3(4)	Cpir	11.2	38.8	24.0	0.8	62.7	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	8.9	<LOD	<LOD	146.4
3(4)–6(7)	Apir	48.2	<LOD	<LOD	0.8	<LOD	<LOD	<LOD	0.6	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	49.6
6(7)–10(14)	E	5.5	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	5.5
10(14)–20(22)	Ha	6.1	<LOD	<LOD	<LOD	<LOD	0.5	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	3.7	<LOD	<LOD	10.3
20(22)–30(33)	Ha	4.4	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.2	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	4.5
30(33)–40	Bhs	3.6	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	3.6
40–50	Bhs	1.4	<LOD	<LOD	0.2	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	1.6
50–60	Bhs	3.7	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	3.7
60–70	BC	1.0	<LOD	<LOD	<LOD	<LOD	0.9	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	1.9
Sod podzol (pit 8)																	
0–1(1.5)	O	36.2	<LOD	<LOD	<LOD	<LOD	5.5	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	41.7
1(1.5)–2(3)	Apir	10.7	<LOD	<LOD	0.1	0.5	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	11.3
4(5)–7	H	40.2	11.6	<LOD	8.2	<LOD	<LOD	<LOD	4.2	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	64.2
2(3)–7	Hpir	42.4	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	42.4
7–9	Ha	5.4	<LOD	<LOD	<LOD	1.7	0.7	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	7.8
9–14	Ha	1.0	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	1.0
14–25	E	1.3	<LOD	<LOD	<LOD	<LOD	0.1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	1.5
25–30	E	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.0
30–40	Bs	1.2	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	1.2
40–50	Bs	0.7	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.7
Sod podzol (Pit 9)																	
0–1(2)	O	2.4	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.7	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	3.1
1(2)–4	Cpir	11.5	<LOD	<LOD	0.3	0.4	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	12.3
4–5	Apir	30.2	22.6	<LOD	<LOD	13.2	3.5	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	69.5
5–7	A	10.7	7.8	<LOD	1.2	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	19.7
7–12	E	1.6	2.6	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	4.2
12–20	EB	1.5	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	1.5
20–30	Bs	3.3	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	3.3
30–40	Bs	12.2	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	12.2
40–50	B	11.4	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	11.4

PAH concentrations in these soils. The first maximum was most frequently confined to pyrogenic organogenic soil horizons (Hepir, Hapir, Apir, He, Ha); these contained up to 40–60 ng g^{-1} . The composition of hydrocarbons in these horizons and the contribution of separate components to PAH associations differed slightly. In most cases, PAHs were represented by naphthalene, anthracene, and pyrene. In particular cases, high-molecular-weight PAHs (perylene, benz(ghi)perylene, benz(k)fluoranthene, benz(a)anthracene) appeared (Figs. 9, 10, Table 3).

Furthermore, occasionally, Cpir and post-pyrogenic O horizons of pits 4 and 5, closer (50 m) to the burned area of 2010, contained up to 150 ng g^{-1} PAH. These sites were af-

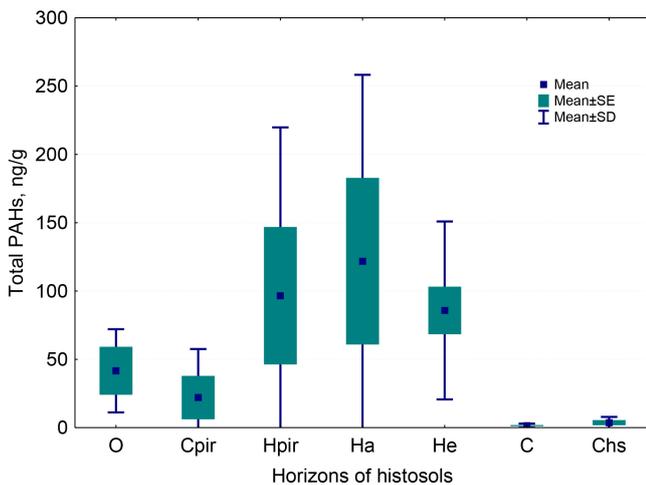
ected by the fire of 2002, perhaps because they were directly nearby the site of a recent burned area (Fig. 3).

At a distance from the site of the last fire, the Cpir horizons (pits 2 and 3) (Table 3), formed in the fire of 2002, contain PAHs in low amounts – up to 2–3 ng g^{-1} , in some cases – to 10–12 ng g^{-1} . Naphthalene prevailed among hydrocarbons, while in soil pit 3, 3-4-nuclear PAHs – chrysene, pyrene, anthracene – were added. The post-fire surface incipient O horizons in these soils contained 3–40 ng g^{-1} PAHs. PAH composition was comprised of naphthalenes and traces of benz(a)anthracene, perylene, and benz(ghi)perylene.

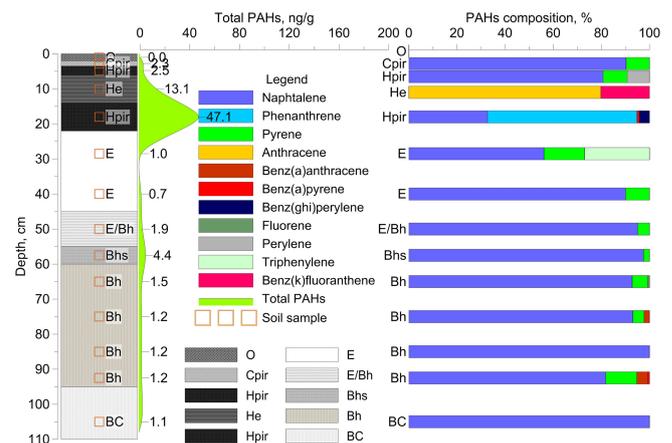
In contrast to histosols, the sod podzols are characterized by eluvio-illuvial translocation of hydrocarbons. For

Table 4. PAH concentrations (ng g^{-1}) in soils of recently burned areas (2012).

Horizon depth, cm	Horizon	Naphthalene	Phenanthrene	Chrysene	Pyrene	Anthracene	Benz(a)anthracene	Benz(a)pyrene	Benz(ghi)perylene	Fluorene	Dibenzofluorene	Perylene	Triphenylene	Benz(e)pyrene	Benz(k)fluoranthene	Coronene	Total PAHs
Histosol, the plot of recently burned areas (2012; pit 13).																	
0–3	O	9.2	<LOD	0.2	0.3	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.2	<LOD	9.8
3–5(6)	Hpir	285.8	<LOD	<LOD	<LOD	46.8	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	332.6
7(9)–16	He	68.5	21.3	<LOD	<LOD	<LOD	<LOD	<LOD	6.2	<LOD	<LOD	<LOD	<LOD	10.0	<LOD	<LOD	106.0
Histosol, the plot adjacent to the burned area (2012; pit 14).																	
0–1	Hpir	31.4	21.0	<LOD	8.3	<LOD	12.5	3.1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	76.3
1–10	He	39.8	<LOD	<LOD	<LOD	<LOD	77.9	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	117.6
10–11	Cpir	70.3	8.5	<LOD	2.8	<LOD	3.5	<LOD	0.2	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	85.3
11–11.5	Hpir	15.2	<LOD	0.1	<LOD	<LOD	<LOD	<LOD	3.7	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	19.0
11.5–20	He	120.5	<LOD	<LOD	<LOD	15.6	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	136.0
20–30	He	66.6	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	66.6
30–40	He	60.1	<LOD	<LOD	1.9	<LOD	3.1	<LOD	1.3	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	66.3
40–45	He	114.3	<LOD	<LOD	<LOD	<LOD	1.3	0.2	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	115.8

**Figure 8.** The categorized box and whisker plot for total PAHs in different horizons of histosols (pits 7, 8, and 9). The number of sample replicates: O-3, Cpir-5, Hpir-6, He-14, Ha-5, Chs-5, and C-12. Horizons Cs and Ch were combined for this analysis, indicated by Chs.

instance, eluvial horizons E contained 0.7 to 5 ng g^{-1} PAHs with a coefficient of variation of 98% and, in some cases, hydrocarbons were not detected. The PAHs were represented in these horizons only by naphthalene and trace amounts of phenanthrene and pyrene. The upper parts of illuvial Bhs horizons had total concentrations in amounts of up to 12 ng g^{-1} , and PAH composition included mainly naphthalene, but benz(a)anthracene, fluorene, benz(e)pyrene and benz(k)fluoranthene occurred in some cases. So, in contrast to background sod podzols, the post-fire soils tended to have some migration of high-molecular weight compounds to illuvial soil horizons (Fig. 10).

**Figure 9.** The profile distribution and PAH composition in post-pyrogenic histic podzols, wildfire 2010 (pit 6).

As opposed to histosols O, Cpir and Apir, horizons of histic and sod podzols had high levels of PAHs that exceeded the range in pyrogenic organogenic horizons (Fig. 11). In podzols, significant differences in PAH concentrations were identified between the A and E and between the A and B horizons ($p < 0.05$).

In the investigated soils, PAHs tended to form groups different in their distribution, which was confirmed by cluster analysis (Fig. 12). PAHs were combined in clusters if the coefficient of correlation in every group was significant at $p < 0.05$. Low-molecular-weight 2- and 3-nuclear compounds had similar distributions in both histosols and podzols throughout the whole profile. The 5-6-nuclear compounds had similar distributions, and were detected only in organogenic horizons Hpir, Ha, and He.

Among the samples, the coefficient of variation was high for high-molecular-weight compounds, especially in

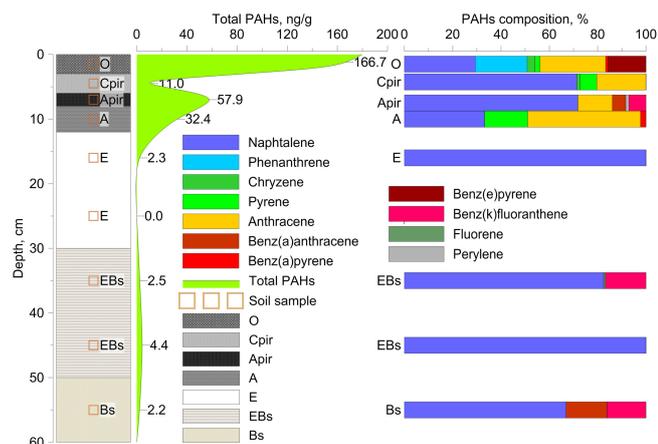


Figure 10. The profile distribution and PAH composition in post-pyrogenic histic podzols from the wildfire of 2002 (pit 5).

Hpir horizons, for benz(a)pyrene (283 %), benz(ghi)perylene (283 %), benz(k)fluorantene (437 %), and chrysene (195 %). The variation of low-molecular-weight compounds was lower; in H horizons, coefficients of variation for naphthalene were 131 and 126 % for phenanthrene.

3.2 The PAH accumulation in soils of burned sites of different times

Certain differences in the intensity of PAH accumulation could be noted in soils of different age burned sites. On the site burned in 2012, the post-fire histosol within the burned area (pit 12) and the histosol situated nearby the burned site and containing charred peat layers from previous fires (pit 11) were studied. In the soil of this most recently burned site, the total PAH concentrations were the highest among all the sites studied. Here, PAH concentrations were 330 ng g^{-1} , and were confined to charry peat horizon Hpir (Table 4). The PAH composition was represented by naphthalene and anthracene. In a deeper horizon He of post-fire histosol without charry material high-molecular weight, compounds benz(ghi)perylene and benz(e)pyrene occurred. The same compounds were detected in soil adjacent to the burned area, but in a lesser amount; the total PAH concentration did not exceed 140 ng g^{-1} . In comparison with the histosols of the 2 year post-burn area (pits 8 and 9), this site is characterized by a higher PAH concentration.

In the case of sod podzols affected by the fires of 2002 and 2010 (pits 5 and 6), the pyrogenic organogenic horizons had similar PAH concentrations (Fig. 9, 10). The differences in the intensities of eluvio-illuvial processes were not detected.

The Kruskal–Wallis ANOVA test indicated significant differences in PAH concentrations, depending on the number of years following the fire. Soils affected by the fire of 2012 differed significantly from years 2002 and 2010, but the differ-

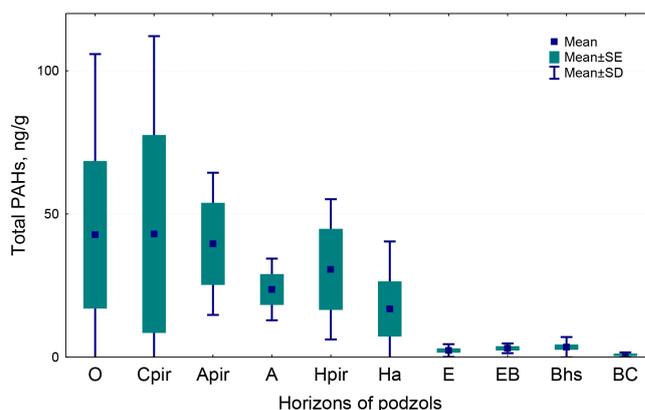


Figure 11. The categorized box and whisker plot for total PAHs in different horizons of podzols (pits 2, 3, 4, 5, and 6). The number of sample replicates: O-6; Cpir-4 Apir-3; A-3; Hpir-3; Ha-6; E-9; EB-5; Bhs-15; BC-4. Horizons Bh, Bs, and Bhs were combined for this analysis into Bhs.

ences between 2002 and 2010 were not detected ($p < 0.05$). Generally, the organogenic horizons from the fire in 2012 had higher PAH concentrations (Fig. 13). In the surface ash horizons Cpir of burned areas from 2002, the tendencies of PAH concentrations decreasing were not detected.

4 Discussion

4.1 Profile distribution of PAHs in soils of different types

The data on PAH concentration and composition in soils not affected by fires corresponded to results obtained for soils of other territories distant from PAH sources (Gennadiev and Tsi bart, 2013; Wilcke, 2007; Rovinskii, 1988; Gabov et al., 2007; Krasnopeeva, 2008).

The production of PAHs in Hpir horizons of *histosols* could be the result of the structure of the smoldering front. These horizons correspond to the pyrolysis front, where wide various volatile compounds and hydrocarbons, including PAHs, are formed. Above this, horizon oxidation and ash formation processes take place with no PAH formation (Rein, 2013). Under the conditions of smoldering and low oxygen access, PAHs may actively form in the combustion zone (Blomqvist et al., 2006; Jenkins et al., 1996; Mastral et al., 1999). Moreover, the intense PAH formation during the long-duration heating has been shown in the literature (Gonzalez-Vila et al., 1991); so, in cases of incomplete burning of peat horizons, the conditions for high PAH production tend to be present. Also, possibly, during the fire, not only the Hpir horizon, but also the entire peat layer was subjected to heating, and PAH formation could take place in organogenic horizons at all depths.

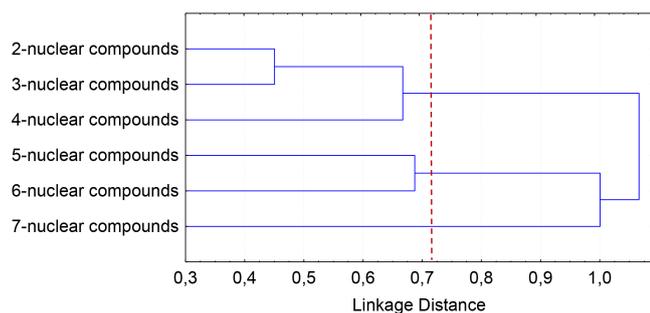


Figure 12. The cluster analysis (complete linkage; $1 - \text{Pearson } r$) for PAH groups in the investigated soil samples. To the left of the red line, the correlation coefficient is statistically significant ($p < 0.05$).

In addition, a possible factor causing different PAH concentrations in peat horizons was the amount of peat remaining after the burning. The greater the residual mass of peat, the greater the sorption of PAHs that was observed to take place. At the same time, allowing for the high variability of absolute PAH concentrations in residual peat horizons, it could be surmised that they tend to accumulate 5-6-nuclear compounds, which could indicate processes of peat combustion. Vane et al. (2013) also pointed out the presence of low- and high-molecular PAHs in soils after peat fire. However, 5-6-nuclear compounds (benz(ghi)perylene, benz(a)pyrene, benz(e)pyrene, benz(k)fluoranthene) could be considered the indication group marking the peat combustion.

The soils with very shallow (up to several cm) peat horizons remaining following fire had low PAH concentrations due to the fact that almost all organic matter had been totally burned out. High coefficients of variation of PAHs in residual peat horizons could be caused by different durations and depths of heating of these horizons at different sites. The depth of changes in soils differs depending on the fire intensity and location characteristics (varying moisture content, microrelief and peat thickness) (Efremova and Efremov, 2006; Grishin et al., 2013).

In the surface incipient horizon O ($20\text{--}70 \text{ ng g}^{-1}$), where mainly 2-3-nuclear compounds (naphthalene, phenanthrene, anthracene) occurred, these compounds were presumably sorbed by new organogenic horizons from the atmosphere. Sorption is one of the leading processes in soil involving PAHs (Trapido, 1999; Wicke, 2000), and the factors determining the rate of sorption are the content of the organic matter and the presence of clay minerals (Maliszewska-Kordybach, 2005; Maliszewska-Kordybach et al., 2010). These were quite high in the newly formed organic horizons.

The PAH concentrations in pyrogenic organogenic horizons (Hepir, Hapir, Apir, He, Ha) of podzols were lower than in analogous horizons of histosols, as these soils had a lesser amount of available organic material for burning and PAH formation.

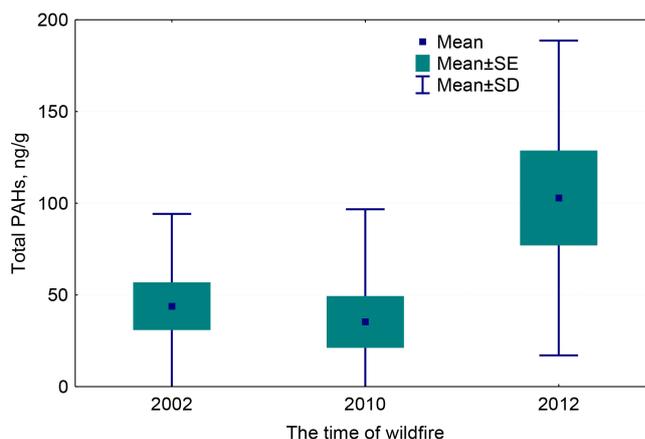


Figure 13. The categorized box and whisker plot for total PAHs in horizons Hpir, Apir, O and Cpir of soils affected by the fires of 2002, 2010, and 2012 (pits 2, 3, 4, 5, 6, 7, 8, 9, 11, and 12). The number of sample replicates: 2002 year -15, 2010 year -19, 2012 year -11.

Also, in comparison with histosols, Cpir and post-fire O horizons of podzols had rather high PAH concentrations. These findings could be explained by the fact that these sites were affected by fire in 2002, but were also directly nearby the site of a burned area of 2010 (Fig. 3). These horizons have a sandy loam texture (Zaidel'man et al., 2006); so, they have a high sorption capacity. Presumably, the accumulation of low-molecular-weight compounds formed during the last fire could take place at these sites.

Also, probably, as the accumulation of heavy PAHs takes place in situ in char and ash horizons, PAHs are translocated across them to the atmosphere, because these horizons act as filters of gases. The accumulation of low-molecular-weight PAHs could be explained by atmospheric input; these compounds are released into the atmosphere with other combustion products, where they are translocated and then deposited at other plots (Rein, 2013).

In contrast to histosols, the sod podzols were characterized by eluvio-illuvial translocation of hydrocarbons, which was also found in the study of Gabov (2007); so, PAH distribution follows the soil-forming processes typical of the wet climates of taiga biomes. The increased migration of PAHs after the fire was, probably, caused by vegetation destruction during the fire and following intense percolation through the soil profile.

4.2 The PAH accumulation in soils of burned sites of different times

The histosols affected by the fire in 2012 had a higher PAH concentration in comparison with the histosols after the fire of 2010. On the one hand, it caused arriving PAHs, especially low-molecular-weight compounds, to possibly degrade after the fire. On the other hand, in the present case, the organic horizons of the most recently burned site were not

completely burned out, which favors the intense sorption and accumulation of polycyclic aromatic hydrocarbons in these soils, but it is worth mentioning that the time of the pyrogenic PAH presence in the soil could differ, depending on the conditions. Thus, even on a geological scale, the elevated PAH concentration in the deposits of the Cretaceous and Jurassic periods could be explained by ubiquitous occurrence of wildfire (Killops and Massourd, 1992; Marynowski et al., 2011; Belcher, 2006). However, according to Garcia-Falcoan (2006), the concentrations in burned organo-mineral soils remained high only during the first 3 months after the fire and, then, PAHs were reduced by soil processes including degradation and migration.

In the case of sod podzols from the 2002 fire, the concentrations of PAHs could also be influenced by the 2010 fires; therefore, trends of PAH degradation with time were not so prominent.

Considering the soils of drained peatlands, it is necessary to emphasize that, in both post-fire sod podzols and histosols, the total PAH concentrations could be rather high – up to hundreds of ng g^{-1} . These peculiarities differ from the features found in our previous studies – in Polistovo Natural Reserve (Pskov region, Russia), where post-fire organogenic peat soils have higher PAH concentrations in comparison with sod-podzol soils (Gennadiev and Tsibart, 2013). Moreover, in the undrained soils, the total PAH concentrations did not exceed 150 ng g^{-1} . Presumably, in the Shatura district, the deep changes in the hydrologic regime occurred after the drainage and the level of groundwater decreased. In these cases, fire affected the soil cover of the area to a great extent, and new horizons having different capacities for PAH accumulation formed. Also, after the catastrophic influence of the fire, the heterogeneity of the soil cover increased, resulting in highly contrasting soil profiles and spatial PAH distribution.

However, it should be noted that even under conditions of catastrophic fires on the drained peatlands in the studied cases, the PAH concentrations, especially high-molecular-weight compounds, were relatively low: for example, benz(a)pyrene concentrations did not exceed 3 ng g^{-1} .

The findings from this study correspond to some previously reported results in the literature. Vane et al. (2013) note that PAH concentrations in peat soils after fire are lower than the amount dangerous for biota. Also, there is no evidence that amounts of PAHs accumulated after the fire are dangerous to humans, as they are lower than hazardous levels determined for soils, but the variation of high-molecular-weight PAHs in soil horizons was high, as these compounds do not occur in all horizons, and their formation is a more complicated process in comparison with low-molecular PAHs.

5 Conclusions

The conclusions of our study are the following:

1. The wildfires on the drained peatlands caused the change in the morphological properties of soils; new soil horizons Cpir, O, Hpir, and Hapir were formed with different accumulation rates of PAHs. The highest PAHs concentrations were seen in charry peat Hpir horizons and in post-fire incipient O horizons.
2. Post-fire histosols and histic podzols differed in their PAH distribution. In both cases, the highest PAH concentrations occurred in the organogenic post-fire horizons, but in cases of histic podzols, their slight accumulation of PAHs in illuvial horizons was possible.
3. 5-6-nuclear compounds were formed in pyrogenic horizons Ha,pir and He,pir. Their production was facilitated in smoldering processes due to a lack of oxygen; this group could be considered an indicator group of peat combustion. 2-3-nuclear PAHs occurred within the whole profile; in sod podzols and histic podzols, their migration to illuvial horizons was observed. In the cases we studied, PAH composition in pyrogenic horizons did not change in different soil types.
4. The trends of higher PAH accumulation in soils were observed in cases of incomplete burning out of peat horizons. PAH sorption in upper horizons of soils near the sites of the most recent fires was observed.

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