

UDC 543.3: 543.635

DOI: 10.15372/CSD20190110

Water Seasonal Dynamics of Organic Compounds Distribution in the Raised Bog of Southern Taiga (Western Siberia)

O. V. SEREBRENNIKOVA^{1,2}, E. B. STRELNKOVA¹, I. V. RUSSKIKH¹, YU. A. KHARANZHEVSKAYA^{3,4}, and E. S. VOISTINOVA³¹*Institute of Petroleum Chemistry, Siberian Branch, Russian Academy of Sciences, Tomsk, Russia**E-mail: rus@ipc.tsc.ru*²*National Research Tomsk Polytechnic University, Tomsk, Russia*³*Siberian Research Institute of Agriculture and Peat – Branch of SFSCA RAS, Tomsk, Russia*⁴*National Research Tomsk State University, Tomsk, Russia*

Abstract

The content and chemical composition of organic oil-soluble constituents (lipids) of the snow cover, peat and water of the Bakchar bog, which is the typical bog for southern taiga (the northeastern spurs of the Great Vasyugan Mire) were explored by gas chromatography-mass spectrometry. As shown, the composition of lipids in waters is exposed to seasonal fluctuations and formed due to compounds generated in a peat deposit and falling with atmospheric precipitation, and also to components of plants. Lipid content is linked to level dynamics of waters, the quantity of fallen atmospheric precipitation, and air temperature. The amount of lipidic components in waters is maximum in the beginning of spring; their composition is almost identical to peat compounds. When water is diluted with melting snow, lipid content is reduced. Herewith, the fraction of the main groups of lipids: *n*-alkanes, and *n*-aldehydes, and also cyclic mono- and sesquiterpenoids present in plants of the early growing season in the snow is increased. An increase in air temperature and a low amount of atmospheric precipitation lead to an increased fraction of lipids produced by water plants and compounds that are a part of conifer resin (dehydroabietic acid and its derivatives) in water. When the amount of rain precipitation is increased, the diversity of composition and lipid content are reduced in water; C₂₅ and C₂₇ *n*-alkanes, and also carboxylic acids are prevailing in this case. A reduction of the amount of atmospheric precipitation at the end of summer is accompanied by an increase in the content of triterpenoids, steroids, long-chain esters of carboxylic acid, and tocopherol in water. Furthermore, betulin and its derivatives typical for birch, and also saturated oil hopane derivatives fallen to water resulting from carrying out technical works appear at the survey plot. A month later, in September, human activity products are removed from the waters; the content of biological triterpenoids, and among them, α - and β -amyrin derivatives enriched with red bilberry and cranberry is drastically increased.

Key words: bog waters, southern taiga in Western Siberia, organic matter, chemical composition, seasonal dynamics

INTRODUCTION

The issue of the quality of natural waters in Western Siberia is particularly acute because of the wide distribution of mires. On the one side,

mires areas accumulate numerous substances coming from the atmosphere and the question of their further migration with waters is still poorly explored. On the other side, due to the specifics of formation conditions of the chemical

composition of waters that is in the close interrelation with transformation processes of plant residues and peat accumulation, the former contain quite a few specific components under natural conditions.

As it is known, plant residues of solid polymers of cellulose nature and their decomposition product that are in equilibrium with an aqueous solution of low and high molecular mass compounds form the basis of peat [1]. Compounds (alkanes, steroids, tocopherols, *etc.*) that are a part of organic matter (OM) are biomarkers and allow the registration of peat accumulation conditions, regional climate changes, and the ecological environmental condition [2, 3]. The remnants of contemporary wetland plants at the initial stage of humification, peat, and man-made products entering the waters from nearby sources and those that are delivered by air masses of anthropogenic impact may be a source of OM in waters. In addition, there may be seasonal fluctuations of OM composition and content related to melting snow cover, atmospheric precipitation, and flowering plants. It is of scientific interest to examine the effect of each source of OM in waters on the composition and content of individual components therein, as there may be several organic matter sources.

The objective of this research was to determine the effect of sources and their seasonal volatility on the content of OM and the chemical composition of the latter in waters as exemplified by the Bakchar bog upper area typical for southern taiga territory.

MATERIALS AND METHODS

Pine-shrub-sphagnum Bakchar bog (north-eastern spurs of the Great Vasyugan Mire) is located in the interstream area of Bakchar and Ikxa rivers, in the boundaries of the Tomsk region, 200 km north-west from Tomsk (Vasyugan Station of Siberian Research Institute of Agriculture and Peat – branch of SFSCA RAS. Tree level at the sampling site is presented by pine (a projective cover of 40 %, a crown closeness of 0.4, a height till 2 m, and a diameter of about 1.5 cm). Grass-shrub level involves *Ledum palustre* (a projective cover of 30 %), *Chamaedaphne calyculata* (60 %), *Andromeda polifolia* (5 %), *Vaccinium uliginosum* (10 %), *Eriophorum vaginatum* (5 %), *Rubus chamaemorus*, and *Oxycoccus microcarpus*. Sphagnum species (95–100 %) stand out among

them; 80 % falls out on *Sphagnum fuscum*, and also there are *Sphagnum magellanicum* and *Sphagnum angustifolium*. The height of bumps is 20 cm.

Peat deposit at a depth of 0–30 cm and 30–60 cm is presented by fuscum peat (upper) (*Sphagnum fuscum* – 85 %, *Sphagnum angustifolium* – 5 %, *Sphagnum magellanicum* – 5 %, and crowberry scrubs – 5 %) with a decomposition degree of 5 %.

Sampling from peat deposit with a depth of about 1 m was carried out in 2016. Sampling from this depth was carried out every month over the period from March to September into specially prepared glassware in accordance with [4]. Peat was sampled from an adjacent well from a depth of 30–50 cm at the end of summer. Snow samples were extracted on the entire depth of snow cover in 5 points at a distance of 1–2 m from each other.

All research steps related to sampling peat and snow, waters, the storage of these species until the beginning of sample preparation, and analytical works themselves were carried out according to the common methodology. Samples of water and melted snow mothballed with chloroform and carbon tetrachloride were placed into glass capacities and transported to the technical lab of the Institute of Petroleum Chemistry of the Siberian Branch of the Russian Academy of Sciences (IPC SB RAS) in Tomsk. The maximum time between sampling and sample preparation was 3 days. The peat was dried after being delivered to the laboratory.

Determining the mass concentration of hydrocarbons (HC) of both natural and technogenic origin in waters was carried out with Nicolet 5700 FT-IR spectrometer (a resolution of 4 cm^{-1} and a sample scan number of 64) in the 3100–2700 cm^{-1} range in CaF_2 cuvettes with an absorption layer thickness of 10 mm. The extraction of HC compounds from water after its separation from suspended components was carried out by filtration using carbon tetrachloride *via* the technique described in [5].

Fat-soluble components (lipids) from the filtered aqueous phase were extracted with three 20 mL portions of a 10 % hexane solution in chloroform. The extraction time was 5 min. The portions of the extracts were combined, dried over anhydrous Na_2SO_4 and evaporated using a rotary evaporator. Lipids from peat were extracted with pairs of a 7 % methanol solution in chloroform. The analysis of the three-component composite of organic compounds was conducted using the Thermo Scientific DFS Magnetic Sector GC-HRMS

system (Germany) provided by the Tomsk Center of Collective Use SB RAS. Paper [6] reports conditions for analysis.

RESULTS AND DISCUSSION

Organic compounds (OC) and total identified compounds (IC) in waters of the raised bog have been determined by IR spectroscopy and gas chromatography-mass spectrometry (GC-MC), respectively Figure 1 gives the determination results in waters of the raised bog from March to September of 2016. The data demonstrate similar seasonal dynamics.

Concentrations of OM and IC vary in a wide range, such as 1.03–0.05 and 0.133–0.003 mg/dm³, correspondingly. The observed distribution nature depends on the quantity of atmospheric precipitation fallen in 2016 considering an additional contribution of the snow melted in April, (according to the weather station at Bakchar village, the All-Russian Research Institute of Hydrometeorological Information – World Data Centre (RIHMI-WDC [7]).

Maximum values were recorded in a sample of water selected in March when the raised bog was still covered with snow (the height of the snow cover at the sampling site was 56 cm). A decrease in the OC concentration begins in April–May because of the dilution of waters with the intensely melting snow cover and then liquid atmospheric precipitation (45.1 and 20.7 mm). Lipid content is drastically increased in June (28.5 mm) and re-

duced when the quantity of precipitation is risen in June–August (165.3 and 61.8 mm, respectively) being somewhat enhanced again in September (31.1 mm).

Lipids of waters from the raised bog, also as peat contacting with the former are a mixture of acyclic and cyclic compounds. Hydrocarbons (HC) involving alkanes (ALK) and squalene (SQ), and also oxygeneous OC presented by fatty acids (FA) and their methyl, isopropyl esters (IPE) and long-chain esters (LCE), aldehydes (ALD), and ketones (KET), and also by phytol, *i.e.* an isoprenoid alcohol, were identified in the composition of the first series. Cyclic compounds involve aromatic HC, tocopherols (TP, vitamin E), steroids (S), sesqui-, di-, and bicyclic (BT), tricyclic (TT), and pentacyclic triterpenoid (PT) compounds.

The group composition of lipids from waters sampled **in March** when the major part of the bog is still covered with snow is almost identical to the content of peat lipids (Fig. 2). Among the latter, PT compounds with the prevalence of taraxerene (Fig. 3, structure I) and its alcohol, keto, and acetyl substituted derivatives are prevailing. Alcohols, ketones, and HC that are a part of PT are present in close concentrations.

The content of other lipids is significantly lower. Methyl and isopropyl esters of *n*-carboxylic acids, bicyclic sesquiterpenoids mainly presented by calcarene-derived compounds, α -muurolene, and β -cadinene are present in trace amounts (compounds II–IV, see Fig. 3). In the composition of C₁₅–C₃₃ *n*-alkanes, C₂₃–C₃₃ homologues with an uneven

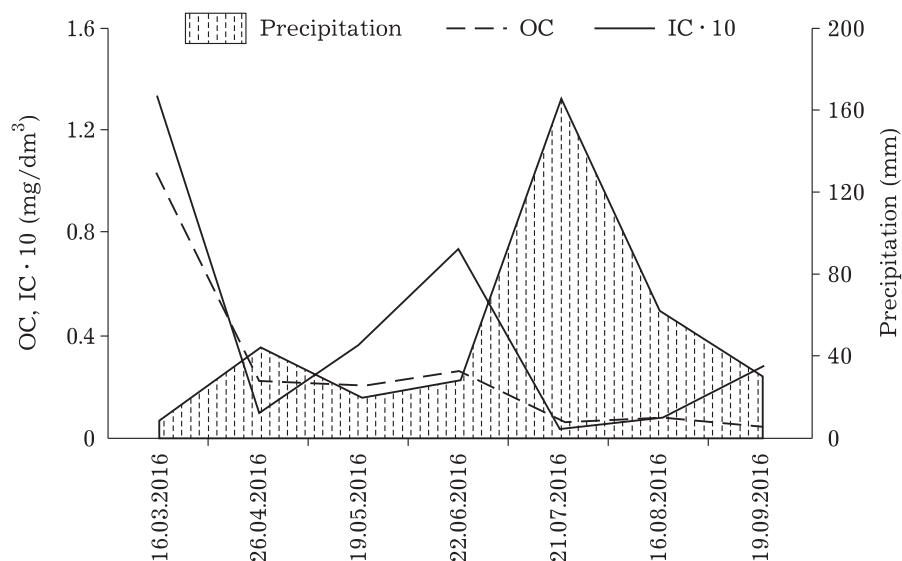


Fig. 1. Dynamics of the content of organic compounds (OC), identified compounds (IC) in the waters of the raised bog considering the quantity of precipitation between March and September 2016.

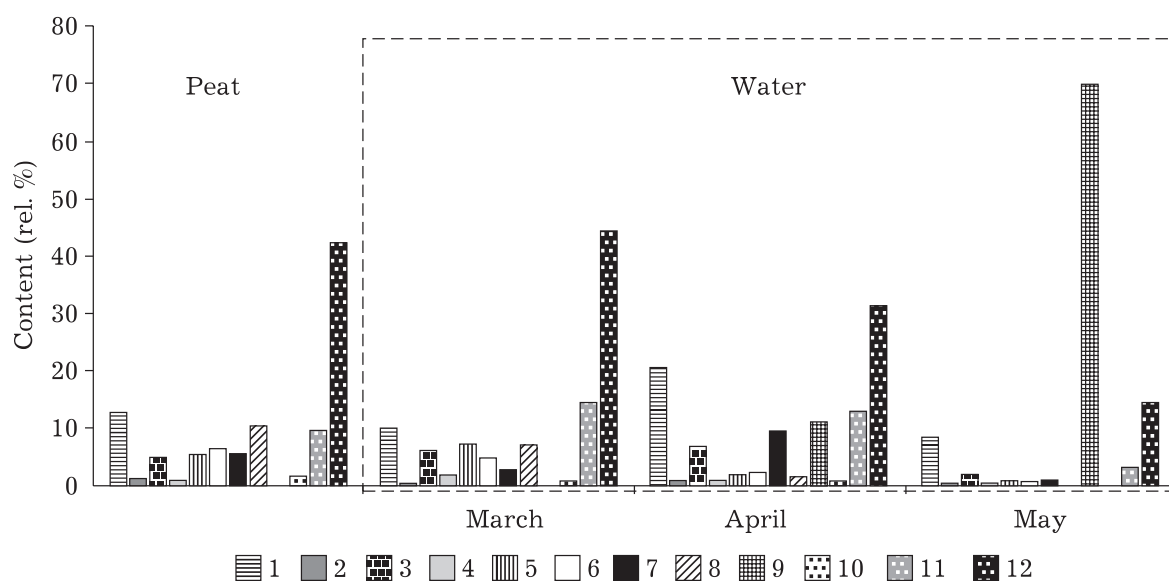


Fig. 2. Relative content of major lipid groups in peat and waters sampled during the spring months. Here and in Fig. 4, 5: 1 – alkanes (ALK), 2 – squalene (SQ), 3 – fatty acids (FA), 4 – methyl and isopropyl esters (E), 5 – long-chain esters (LCE), 6 – ketones (KET), 7 – aldehydes (ALD), 8 – Tocopherols (TP), 9 – bicyclic terpenoid (BT) compounds, 10 – tricyclic terpenoid (TT) derivatives, 11 – steroids (S), and 12 – pentacyclic terpenoid (PT) compounds.

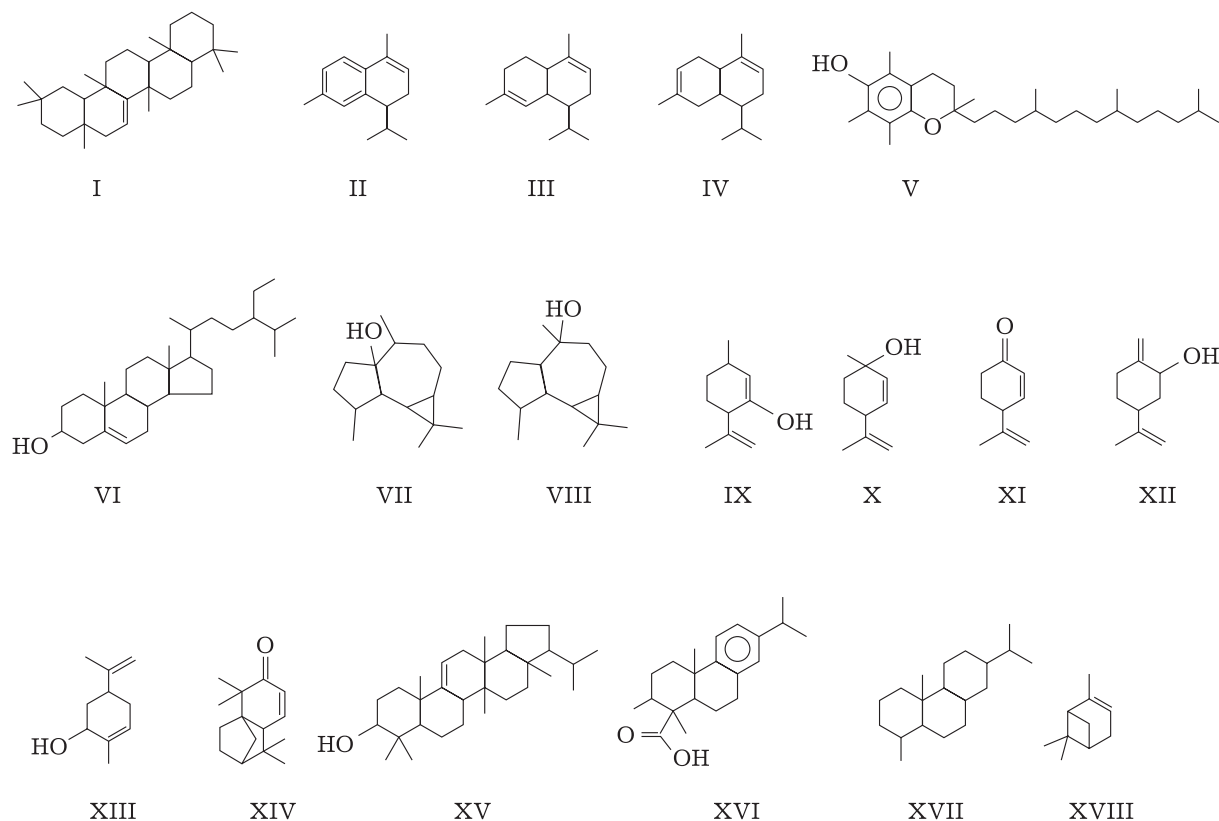


Fig. 3. Structures of the main representatives of cyclic compounds identified in the peat and/or waters: I – taraxerene II – α -calacorene, III – α -muurolene, IV – β -cadinene, V – α -tocopherol, VI – sitosterol, VII – palustrole, VIII – ledol, IX – trans-*p*-menta-2,8-dienol, X – 4-isopropenyl-1-methyl-2-cyclohexene-1-ol, XI – 4-isopropenyl-cyclohexanone, XII – 2-methylene-5-(1-methylethenyl)cyclohexanol, XIII – *p*-menta-6,8-dien-2-ol, XIV – 2,2,7,7-tetramethyl-tricyclo[6.2.1.0(1,6)]undec-4-en-3-one, XV – fern-7-en-3-ol, XVI – dehydroabietic acid, XVII – 18-norabietan, and XVIII – pinene.

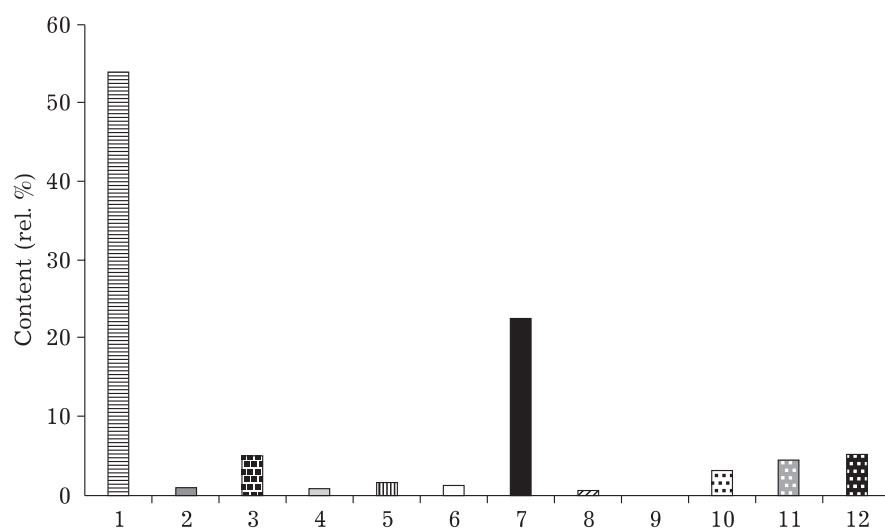


Fig. 4. Relative content of the main groups of lipids in the snow cover of Bakchar bog. Symbols can be seen in Fig. 2.

number of carbon atoms are prevailing and among these species, C_{31} . In the set of long-chain esters (C_{26} – C_{32}), the main ones are C_{26} – C_{28} represented by various isomers consisting of *n*-, *iso*-, and *anti-iso*-aliphatic residues of acids and alcohols.

In the composition of the C_{21} – C_{31} *n*-alkan-2-ones, as *n*-alkanes, odd-numbered homologues are prevailing, but the maximum in the distribution of former falls on C_{27} . In the molecular mass distribution of *n*-aldehydes, odd homologues are present in the subordinate amount and the main compounds are C_{24} and C_{26} . Tocopherols involve α -, β -, γ -, and δ -forms, of which about 70 % is presented by α -tocopherol (structure V, Fig. 3). Among steroids, sitosterol is prevailing (compound VI, Fig. 3).

An increase in the groundwater level (–3 cm) **in April** during melting snow cover and defrosting the peat deposit is accompanied by a drastic reduction in the total content of lipids in the waters. Along with that, the fraction of *n*-alkanes and *n*-aldehydes is increased. These entities are the major frameworks of lipids in snow (Fig. 4). There are somewhat more C_{25} and C_{27} *n*-alkanes in the composition of C_{23} – C_{33} *n*-alkanes compared to their content in March. The latter species are drastically prevailing among *n*-alkanes in snow cover. Pentacyclic triterpenoids contain a reduced relative content of taraxerenes that are present in a relatively low concentration in snow. There are prevailing α - and β -amyrin homologues and alcohols as a whole. Steroids in April waters have an increased relative content of cholesterol typical for to animal forms and their activity products. Cholesterol is the main steroid as a part of

lipids of snow cover. High levels of aldehydes and cholesterol in snow indicate the potential pollution of snow cover with animal waste accumulated therein during a long winter time [8 and 9].

The appearance of bicyclic sesquiterpenoids, such as palustrol and ledol in appreciable quantities (compounds VII and VIII, see Fig. 3) in swamp waters during April indicates the beginning of the vegetation period. There are no such systems in peat and waters during March. These volatile compounds make up about 70 % of essential oil of the shoots of wild rosemary [10] that is wide spread in the investigated bog and represents 30 % of the herb-shrub level thereon.

Thus, if the OC composition in the waters in March is mainly formed due lipids formed in the peat deposit of the bog, components brought with atmospheric precipitation and animal waste products also make significant contributions. In addition to these two sources, the awakening of marsh plants in April leads to the ingress of lipid components liberated hereof into waters.

In May, when wild rosemary begins to flourish, the BT fraction presented by palustrol and ledol per 99 % is drastically increased in the composition of organic compounds. In this period of life, upon a decrease in the groundwater level by 11 cm in relation to the average surface of the bog, monocyclic terpenes appear in the water. These species are structural analogues of menthol and menthone with one or two unsaturated bonds (compounds IX–XIII, see Fig. 3). The total content of these compounds is closer according to the value and the concentration of PT species. Unlike March, water in April contains trace tricyclic

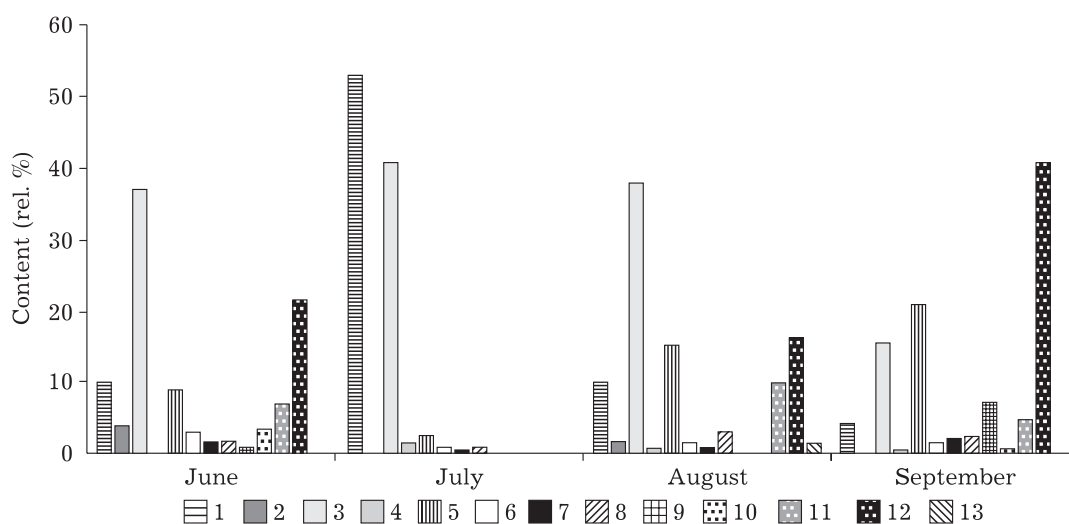


Fig. 5. Relative water content of the main groups of lipids in the summer season. See designations in Fig. 2.

2,2,7,7-tetramethyltricyclo[6.2.1.0(1,6)]undec-4-en-3-one (compound XIV, see Fig. 3) and pentacyclic fern-7-en-3-ol (structure XV, see Fig. 3), present, as shown in [11, 12], in plants of the family of composite flowers along with mono- and bicyclic structures.

The dilution of waters with atmospheric precipitation was minimum in June. On the contrary, the average temperature over the past period (from previous water sampling) increased from 5.8 to 16.3 °C. The groundwater level was decreased to -27 cm; the fraction of carboxylic acids, their length-chain esters and squalene was drastically increased in the composition of organic compounds (against the background of an increase in the total lipid content); volatile monocyclic terpenoids, palustrole, ledol, and tricyclic 2,2,7,7-tetramethyl[6.2.1.0(1,6)]undec-4-ene-3-one disappeared (Fig. 5).

The dilution of waters with atmospheric precipitation was minimum **in June**. On the contrary, the average temperature over the past period (from previous water sampling) increased from 5.8 to 16.3 °C. The groundwater level was decreased to -27 cm; the fraction of carboxylic acids, their length-chain esters and squalene was drastically increased in the composition of organic compounds (against the background of an increase in the total lipid content); volatile monocyclic terpenoids, palustrole, ledol, and tricyclic 2,2,7,7-tetramethyl[6.2.1.0(1,6)]undec-4-ene-3-one disappeared (Fig. 5).

Compared to the spring period, there is almost a 30-fold increase in the content of TT typical for the resin of coniferous plants presented by dehydroabietic acid (compound XVI, Fig. 3)

and its derivatives, among which present 18-nor-biatane is presented at the maximum concentration in June (structure XVII, Fig. 3). Pinene that is the main component of pine oil (compound XVIII, see Fig. 3) appears. This coincides with the beginning of the growth of pine needles in June [13]. Unlike the prevalence of palmitic (C_{16}), myristic (C_{14}) and stearic (C_{18}) acids [14, 3] typically observed among acids of plant and peat that are also prevailing in acids of spring waters, the total content of these species in June is not higher than the concentration of capric acid (C_{10}). The relative content of the C_{23} homologue produced by plants in the composition of alkanes has been increased; apart from that, the molecular mass distribution of *n*-alkanes has almost not changed.

In June, calacorene-derived compounds, β -cadinene, and α -muurolene are prevailing in the composition of BT both in peat and waters in March; however, *t*-muurolene, *i.e.*, the oxidation product of α -muurolene, appears [15]. The relative content of taraxerene derivatives as a part of PT compounds is close by value to the level observed in waters in March and peat.

Hence, an increased environmental temperature results in an increase of the fraction of peat organic components in water. The content of compounds produced by aquatic plants and included in the composition of plant resins is increased. Components of ester oils that fall into water from plants in the beginning of vegetation period disappear from the composition of lipids of waters in June.

In July, when the monthly average temperature is insignificantly increased in comparison

with June (19.6 and 16.3 °C, correspondingly) but upon a drastic increase in the quantity of fallen atmospheric precipitation and a rise in the groundwater level (–19 cm), the total content of lipids is decreased in water. The content of the latter species is presented by *n*-alkanes by 52 %. Among these HC, C₂₅ and C₂₇ homologues are significantly prevailing as and in the investigated sample of snow cover. This molecular-mass distribution of *n*-alkanes, wherein C₂₅ and C₂₇ homologues are prevailing, and other homologous compounds are present at low concentrations, is typical for atmospheric precipitation in swampy areas of the south-west of the Tomsk region. Carboxylic acids with prevailing pelargonic acid present around 40 % of lipids. Long-chain, methyl and isopropyl esters of carboxylic acids, alkanones, aldehydes and trace BT compounds presented by retene were determined among other 8 %. There are no squalene, steroids, BT, and PT or their concentrations are too low to be determined by GC-MS. The content of aldehydes, one of the main groups of lipids isolated from snow is minor in July water, whereas there are no cholesterol derivatives.

In August, when the quantity of atmospheric precipitation and the groundwater level (–28 cm) were somewhat reduced; lipid concentration therein was increased. The group composition of lipids in swamp water was increased. However, the works for the arrangement of the investigated area in the borderlines of the Vasyugan Station that began this year led to the appearance of isomers of saturated C₂₇ (Ts and Tm), C₂₉ (17 α (H), 21 β (H), and 17 β (H), 21 α (H)), C₃₀ (17 α (H), 21 β (H) and 17 β (H), 21 α (H)), and C₃₁ (R and S) hopanes typical for petroleum oil fractions [16]. In addition, a ratio of homologues of alkanes with an uneven number of carbon atoms to even ones, between 7.6 and 2.8, which may also be the consequence of water pollution with oil products.

Among biological lipid species present in water in August, the relative content of steroids was somewhat increased, betuline and betuline acid methyl ester that are present at maximum concentrations in birch bark *Betula pubescens*. The latter is common in the border part of the raised bog (a projective cover of 30 %) at a distance of about 500 m from the sampling point [17]. The C₃₁ homologue is prevailing in the composition of *n*-alkanes in peat and spring waters.

A further decrease in the quantity of atmospheric precipitation and the groundwater level

(–31 cm) **in September** had an effect on an insignificant increase of the total content of lipids with a drastic rise of the PT fraction therein. The LCE content was somewhat increased and the C₂₈ homologue is prevailing both in spring and summer waters. Along with that, the quantity of bicyclic sesquiterpenoids mainly presented by cadinene and calacorene compounds was enhanced. The latter systems are prevailing in peat and numerous vegetation forms. The composition of PT compounds, the fraction of which is close to that detected for peat is notable for a low content of taraxerene homologues and for the prevalence of α - and β -amyrin compounds. The latter systems enrich cranberry rarely found within the sampling point, and also red bilberry widespread in the adjacent areas of the investigated the raised bog [18]. The relative content of carboxylic acids, in the composition of which similarly to peat palmitic acid is prevailing, is reduced. The higher content of caprylic and pelargonic acids compared to peat is inherited from summer waters. Oil hopane compounds registered in waters in August were detected only in trace quantities in September.

CONCLUSION

Various organic compounds constitute lipidic components in the snow cover, peat and the waters of Bakchar bog. The composition and content of the former species in waters are exposed to significant seasonal fluctuations. Lipid content in waters is formed due to compounds that are being washed out from peat, components of marsh plants, the involvement of individual species that depend on the vegetation period of the former, and compounds fallen with atmospheric precipitation. A ratio of the contribution of these sources is varied with time and the content of lipids in water is determined by the time of snow cover melting and is further due to the intensity of atmospheric precipitation.

In the beginning of spring, prior to snow cover melting, the content of lipid components in water is maximum and their content is almost identical to that in peat. Lipids are mainly comprised of pentacyclic triterpenoids (around 50 % of the total amount of lipids) and steroids (16 %). The dilution of water with extensively melting snow leads to a decrease in the total amount of lipids. In addition to peat, they are mainly comprised of components that are introduced with atmospheric precipitation in the winter season. The former are

presented by *n*-alkanes and *n*-aldehydes. Furthermore, these moieties contain cyclic mono- and sesquiterpenoids that are excreted by awakening plants and may reach maximum concentrations (over 70 % of the total amount of lipids) in May during the flowering of some species.

An increase in the environmental temperature in the beginning of summer upon a low content of atmospheric precipitation results in a rise in the fraction of oil organic components and *n*-carboxylic acids in water. The fraction of lipids produced by water plants (an increase in concentration by C₂₃ *n*-alkanes) and that of compounds being a part of the resin of softwood species (dehydroabietic acid and its derivatives) are also increased. Components of essential oils entering the water from plants in the early beginning of the vegetation period vanish from the composition of lipids in waters.

An intense increase in the quantity of fallen atmospheric precipitation causes a decrease in the lipid content in swamp waters. The main group that makes up 52 % of the total lipid content is *n*-alkanes; slightly less (42 %) falls on carboxylic acids.

At the end of summer, when the quantity of atmospheric precipitation was reduced, lipid content in water was somewhat increased. The content of peat components (C₃₁ *n*-alkanes and taraxerenes) was increased in the composition of lipids. Compared to the previous summer months, the relative content of steroids, long-chain esters (LCE) of carboxylic acids, tocopherol was increased; betulin and its derivatives appeared being present at high concentrations in birch bark. There were detected saturated C₂₇ and C₂₉–C₃₁ hopane compounds. These systems are typical for oil product and indicate the pollution of waters resulting from carrying out technical works in the investigated area in August. In a month, in September the content of biological PT compounds and among them α - and β -amyrin systems that enrich red bilberry and cranberry was drastically increased in waters. The content of carboxylic acids was reduced,

their composition being becoming close to peat one. Waters became purified from anthropogenic activity products. Such a quick disappearance of oil products from waters may be due to the removal of the former with aqueous flow or sorption with peat contacting with water.

REFERENCES

- 1 Lishtvan I. I., Bazin E. T., Gamayunov N. I., Terent'ev A. A. *Fizika i Khimija Torfa*, Moscow, 1989.
- 2 Duchko M. A. *Geokhimiya Biomarkerov v Torfakh Yugovostochnoi Chasti Zapadnoi Sibiri* (Abstract of Candidate's Dissertation in Chemistry), Tomsk, 2017.
- 3 Serebrennikova O. V., Strel'nikova E. B., Russkikh I. V., Duchko M. A., *Solid Fuel Chem.*, 2017, Vol. 51, No. 4, P. 195–204.
- 4 GOST 31861–2012. Interstate Standard. Water. General Requirements for Sampling, Moscow: Standartinform, 2013.
- 5 PND F 14.1:2.5–95. Metodika Vypolneniya Izmerenii Massovoi Kونسentratsii Nefteproduktov v Prirodnykh i Stokhnykh Vodach Metodom IK Spektrometrii, Moscow, 2004.
- 6 Serebrennikova O. V., Strel'nikova E. B., Duchko M. A., Kadychagov P. B., and Russkikh I. V., *Water Resour.*, 2015, Vol. 42, No. 6, P. 798–809.
- 7 Materialy Website. URL: <http://meteo.ru/data/162-temperature-precipitation#> (accessed 04.06.2018).
- 8 Cooperband M. F., McElfresh J. S., Millar J. G., Cardé R. T., *J. Ins. Physiol.*, 2008, Vol. 54, P. 1184–1192.
- 9 Kimura R. *Canad. J. Anim. Sci.*, 2001, Vol. 81, P. 411–420.
- 10 Bereznegovskaya L. N., Berezovskaya T. P., Doshchinskaya N. V. *Lekarstvennye Rasteniya Tomskoi oblasti*, Tomsk, 1972.
- 11 Witte S., Moco S., Vervoort J., Matern U., Martens S., *Planta*, 2009, Vol. 229, No. 5, P. 1135–1146.
- 12 Yu J. Q., Liao Z. X., Cai X. Q., Lei J. C., Zou G. L., *Environ. Toxicol. Pharmacol.*, 2007, Vol. 23, P. 162–167.
- 13 Pakharkova N. V., Filippova M. A., Subbotin M. A., Pakharkov M. A., Sorokina G. A., *Ulyanovsk Medico-Biological J.*, 2011, No. 4, P. 111–117.
- 14 Serebrennikova O. V., Strel'nikova E. B., Gulaya E. V., Kadychagov P. B., Preys Yu. I., Duchko M. A., *Khimija Rastitel'nogo Syr'ya*, 2014, No. 3, P. 139–144.
- 15 Okoh O. O., Sadimenko A. P., Asekun O. T., Afolayan A. J. *African. J. Biotechnol.*, 2008, Vol. 7, P. 1500–1502.
- 16 Bolshaya Entsiklopediya Nefti i Gaza. URL: <http://www.ngpedia.ru/id646117p1.html> (accessed 04.06.2018).
- 17 Rastitel'nye Resursy Rossii: Dikorastushchie Tsvetkovye Rasteniya, ikh Komponentnyi Sostav i Biologicheskaya Aktivnost, Sankt-Peterburg – Moscow, 2008, Issue 1.
- 18 Materialy Website. URL: <https://refdb.ru/look/1774540.html> (accessed 04.06.2018).