PEER-REVIEWED ACADEMIC JOURNAL
ISSN 2218-4422 (Print)
ISSN 2541-9307 (Online)

ENVIRONMENTAL DYNAMICS AND GLOBAL CLIMATE CHANGE

Volume 12
Issue 1
2021

https://edgccjournal.org

Founders:

Yugra State University. 628012, Russia, Khanty-Mansi autonomous Area, Khanty-Mansiysk, Chekhova str., 16. Phone/fax: +7(3467)377-000, ext. 101, WEB: www.ugrasu.ru

National Research Tomsk State University. 634050, Russia, Tomsk, Lenin Ave., 36. Phone: +7(3822)58-98-52, fax: +7(3822)52-95-85, WEB: www.tsu.ru

Institute for Water and Environmental Problems of the Siberian Branch of the Russian Academy of Science. 656038, Russia, Barnaul, Molodezhnaya str., 1. Phone: +7(3852)66-64-60, fax: +7(3852)24-03-96, WEB: www.iwep.ru

Arctic Research Center of the Yamal-Nenets autonomous Area. 629001, Russia, Yamal-Nenets autonomous District, Salekhard, Respublic str., 73. Phone/fax: +7(34922)441-32, WEB: www.arctic.yanao.ru

Federal Supervisory Service on Mass Media, Information Technologies and Mass Communication (Roskomnadzor)
ПИ № ФС 77-73235 from 06.07.2018

Indexing: Science Index (elibrary), Google Scholar, Ulrich's Periodicals directory, WorldCat, EBSCO

ПЕРИОДИЧЕСКОЕ НАУЧНОЕ ИЗДАНИЕ
ISSN 2218-4422 (Print)
ISSN 2541-9307 (Online)

ДИНАМИКА ОКРУЖАЮЩЕЙ СРЕДЫ И ГЛОБАЛЬНЫЕ ИЗМЕНЕНИЯ КЛИМАТА

Том 12
Выпуск 1
2021

Журнал издается с 2008 года
https://edgccjournal.org

Учредители:
ФГБОУ ВО «Югорский государственный университет».
628012, Россия, Ханты-Мансийский автономный округ — Югра, г. Ханты-Мансийск ул. Чехова, 16.
Тел./факс: +7(3467)37-70-00 (доб. 101), WEB: www.ugrasu.ru

ФГАОУ ВО «Национальный исследовательский Томский государственный университет».
634050, Россия, г. Томск, пр. Ленина, 36. Тел.: +7(3822)58-98-52, факс: +7(3822)52-95-85, WEB: www.tsu.ru

ФГБУН Институт водных и экологических проблем Сибирского отделения Российской Академии наук. 656038, Россия, г. Барнаул, ул. Молодежная, 1. Тел.: +7(3852)66-64-60, факс: +7(3852)24-03-96, WEB: www.iwep.ru

ГКУ Ямало-Ненецкого автономного округа «Научный центр изучения Арктики».
629008, Россия, Ямало-Ненецкий автономный округ, г. Салехард, ул. Республики, 73. Тел./факс: +7(34922)441-32, WEB: www.arctic.yanao.ru

Журнал зарегистрирован Федеральной службой по надзору за соблюдением законодательства в сфере массовых коммуникаций, связи и охране культурного наследия. Свидетельство о регистрации ПИ № ФС 77–73235 от 06.07.2018

Индексируется: Science Index (РИНЦ), Google Scholar, Ulrich's Periodicals Directory, WorldCat, EBSCO

Архив журнала «Динамика окружающей среды и глобальные изменения климата» размещен в сети Интернет www.elibrary.ru, https://edgccjournal.org/EDGCC/issue/archive

CONTENTS

EXPERIMENTAL WORKS

D.K. Davydov, A.V. Dyachkova, O.A. Krasnov, D.V. Simonenkov, A.V. Fofonov, S.S. Maksyutov

Application of the automated chamber method for long-term measurements of CO_2 and CH_4 fluxes from wetland ecosystems of the West Siberia 5

P.V. Bolshanik, S.B. Kuznetsova, D.D. Karaseva

Natural features of the orchid refugium on the territory of the natural park “Samarovsky chugas» 15

E.V. Agbalyan, E.A. Zarov, I.V. Filippov, Yu.A. Pechkina, E.V. Shinkaruk, K.V. Yulbarisova, N.A. Khnycheva, E.D. Lapshina

Biogeochemical assessment of the main plants at the Nadym district's reindeer pastures (Yamal-Nenets autonomous okrug) 27

DISCUSSIONS

D.M. Frolov

Impact of snow cover and air temperature on ground freezing depth and stability in mountain area 43

ЭКСПЕРИМЕНТАЛЬНЫЕ РАБОТЫ

D.K. Davydov, A.V. Dyachkova, O.A. Krasnov, D.V. Simonenkov, A.V. Fofonov, S.S. Maksyutov

Application of the automated chamber method for long-term measurements of CO_2 and CH_4 fluxes from wetland ecosystems of the West Siberia 5

P.V. Bolshanik, S.B. Kuznetsova, D.D. Karaseva

Natural features of the orchid refugium on the territory of the natural park “Samarovsky chugas» 15

E.V. Agbalyan, E.A. Zarov, I.V. Filippov, Yu.A. Pechkina, E.V. Shinkaruk, K.V. Yulbarisova, N.A. Khnycheva, E.D. Lapshina

Biogeochemical assessment of the main plants at the Nadym district's reindeer pastures (Yamal-Nenets autonomous okrug) 27

ДИСКУССИИ

D.M. Frolov

Impact of snow cover and air temperature on ground freezing depth and stability in mountain area 43

УДК 502.057; 502.501
DOI: https://doi.org/10.17816/edgcc48700

APPLICATION OF THE AUTOMATED CHAMBER METHOD FOR LONG-TERM MEASUREMENTS OF CO_2 AND CH_4 FLUXES FROM WETLAND ECOSYSTEMS OF THE WEST SIBERIA

D.K. Davydov[1], A.V. Dyachkova[1], O.A. Krasnov[1], D.V. Simonenkov[1], A.V. Fofonov[1], S.S. Maksyutov[2]

[1] V.E. Zuev Institute of Atmospheric Optics SB RAS, Tomsk, Russia
[2] National Institute for Environmental Studies, Tsukuba, Japan

Corresponding author: A.V. Fofonov, e-mail: alenfo@iao.ru

Citation: Davydov D.K., Dyachkova A.V., Krasnov O.A., Simonenkov D.V., Fofonov A.V., Maksyutov S.S. 2021. Application of the automated chamber method for long-term measurements CO_2 and CH_4 fluxes from wetland ecosystems of the West Siberia // Environmental dynamics and global climate change. V. 12. N 1. P. 5–14. DOI: https://doi.org/10.17816/edgcc48700

The use of automated systems when studying greenhouse gas (GHG) fluxes allows accurate measurements at minimal disturbance of the soil surface to be carried out and high resolution datasets for extended periods of time to be obtained. Due to the above advantages, chamber measurements play an important role while establishing long-term observations in the framework of such research infrastructures as Integrated Carbon Observation System (ICOS).

CO_2 and CH_4 fluxes from Bakchar bog, West Siberia, were measured by means of a solar powered automated system (Flux-NIES) consisted of six static chambers installed along the transect and connected to the LI-820 NDIR analyzer and modified commercial methane sensor TGS-842, respectively.

The water vapor can significantly affect the measurement accuracy of most gas-analyzers. It is recommended the ambient air to be completely or moderately dehumidified before supplying it to a measurement cell. We used a three-stage drying unit before supplying the air sample to the analyzers: an auto drain water trap, the Nafion dryer, and the chemical desiccants.

Observations were carried out during the growing season (from May to October) in 2013–2019 at the sedge fen (E-site). Correlation analysis made it possible to derive the dependences of CO_2 and CH_4 fluxes on the local hydrometeorological conditions.

The seasonally integrated net CO_2 uptake shows that Siberian wetland ecosystems are a strong sink of atmospheric carbon. Drier environmental conditions lead to a decreasing carbon sink and higher soil water content enhances the net CO_2 uptake efficiency. Similar effect was revealed for methane emissions, except for the case of June 2018, when unexpectedly low values of CH_4 fluxes were observed under the heavy flood conditions those resulted in a weak methanogenesis due to a nutriment scarcity in the peat beds and significant changes in soil pH.

GHG fluxes have a local spatial variability: higher net CO2 uptake and CH_4 emissions are observed at wet mesotrophic locations with higher photosynthesis and respiration rates; lower net uptake of CO_2 and CH4 emissions were observed in the meso-oligotrophic landscape.

Keywords: automated chamber method; surface-atmosphere GHG exchange, water content in peatlands.

ACCEPTED ABBREVIATIONS

WL — water table level,
FC — foliage cover.

INTRODUCTION

The long-term and high-precision measurements of GHG fluxes and effluents and their evolution be requisite for understanding the causes of Earth's climate change and planning the necessary measures to prevent dire consequences. Standardized measurements and calculations of gas fluxes increase the availability and usability of collected data for existent processes modeling. Automated chamber systems operating in closed dynamic mode are suggested as the main method for GHG fluxes measuring at the soil surface – atmosphere boundary at monitoring stations included in the ICOS (Integrated Carbon Observation System) [Pavelka et al., 2018].

The chamber methods of trace gases fluxes measurements at the soil surface – atmosphere boundary have been carried out for almost 100 years [Vadyunina and Korchagina, 1961, pp. 137–140; Pavelka et al., 2018]. Different research methods including statistic and dynamic ones are used to record the major GHG fluxes. The chamber methods are relatively cheap and easy to operate. These methods can be adapted for a wide range of studies from local to global spatial scales in combination with mathematical modeling methods. The standardization of chamber research methods facilitates their application in various monitoring networks of various Earth's ecosystems.

Carbon dioxide (CO_2) and methane (CH_4) are greenhouse gases that are largely controlled by the chamber method. CO_2 is one of the most common gases and takes on enormous importance in the land–ocean–atmosphere system. It has both natural and anthropogenic sources. Also, CO_2 plays an essential role in a number of biological processes (photosynthesis, respiration, etc.) in the natural carbon cycle. Atmospheric carbon dioxide concentrations increased by 40%, from 278 million^{-1} in 1750 to 406 million^{-1} in 2017 [NOAA/ESRL, 2017].

CH_4 also has a strong greenhouse effect and plays a significant part in determining the troposphere oxidative capacity and stratospheric ozone depletion. Like carbon dioxide, it has both natural and anthropogenic sources. There are still a great number of regions with $\boldsymbol{CH_4}$ sources that are poorly understood. For instance, the vast areas of the Russian Arctic are poorly studied. There, the presence of natural wetlands and the use of fossil fuels lead to significant atmospheric $\boldsymbol{CH_4}$. Over the same period of time as the observed increase in the $\boldsymbol{CO_2}$ content, the atmospheric $\boldsymbol{CH_4}$ concentration increased by 150% – from 722 billion^{-1} in 1750 to 1859 billion^{-1} in 2017 [NOAA/ESRL, 2017].

Thus, the atmospheric concentrations of CO_2, CH_4 and other greenhouse gases have increased since pre-industrial era due to anthropogenic emissions associated with the burning of fossil fuels used as an energy source and with changes in land using. The observed changes in the atmospheric GHG concentrations are the result of a disturbance in the dynamic balance between anthropogenic emissions and natural processes that lead to the partial removal of these gases from the atmosphere [Ciais et al., 2013].

The chamber measurement methods are beneficial determining temporal and spatial discontinuities of GHGs fluxes and dividing the total $\boldsymbol{CO_2}$ fluxes into their components (respiration/absorption), etc. The use of automated systems when studying GHG fluxes at the surface-atmosphere boundary allows to make accurate measurements at minimal disturbance of the soil surface regardless of the weather and time of day and receive high-resolution data for extended periods of time.

The literature data suggests that the Russian scientific groups use automated chambers of different constructions for gas fluxes measurements. For instance, gas analyzers LI-8100A (Licor Inc., USA) with integral small chamber in the form of an inverted bowl are wildly used [Mahnykina et al., 2016; Ivanov et al., 2017].

Other researchers develop and manufacture chambers by themselves for specific targets [Maximov et al., 2012; Molchanov, 2017]. The automation of chambers consists in developing a mechanism which can open and close a particular chamber according to a given time cycle. For this purpose, either a pneumatic drive or an electromechanical one is usually used. It is worth noting that a major number of researchers prefer chambers of pneumatic design since the use of DC motors is associated with a number of problems.

Two solutions have been found for the internal volume aeration of chambers. First involves lifting up the top cover-cap, second- lifting the entire cap above the base [Bealan et al., 2017; Dyukarev et al., 2019].

A group of Russian and Japanese scientists under the general supervision of Prof. G. Inoue (Glagolev, 2010, p.3) should be recognized as the pioneers in the application of the automated chamber method for the study of gas fluxes at the soil – atmosphere boundary in Russia (Western Siberia). The first automatic system prototype was installed on the territory of the Bakchar bog (Tomsk region) in 1997 [Nakano et al., 1998]. Since then, the structure of the measuring complex has undergone numerous changes both in the hardware composition and in ensuring the continuity of autonomous measurements.

On if and when occurred basis, engineered automated complex received its own name "Flux-NIES". This article provides an immediate description of the complex structure and discusses the results obtained from long-term observations of measuring seasonal gas fluxes in wetland ecosystems of the southern taiga zone of Western Siberia.

MATERIALS AND METHODS

The "Flux-NIES" measuring system with 6 automatic chambers was developed jointly by the National Institute for Environmental Studies (NIES, Tsukuba, Japan) and V.E. Zuev Institute of Atmospheric Optics of Siberian Branch of the Russian Academy of Science (IAO SB RAS, Tomsk, Russia) in the late 1990s and early 2000s to study methane and carbon dioxide fluxes at the soil – atmosphere boundary [Maksyutov et al., 1999; Krasnov et al., 2013]. Since then, its composition has been repeatedly changed and modernized. Currently, two almost identical measuring systems are operated at the Plotnikovo field station (Fig. 1).

The measuring equipment includes a modified semiconductor sensor TGS-842 (Figaro Inc., USA) with a sensor element based on a tin dioxide slice (SnO_2) as a CH_4 gas-analyzer [Suto and Inoue, 2010]. A non-dispersive infrared NDIR gas-analyzer LI-820 (Licor Inc., USA) is applied for measuring the CO_2 concentration. The air sample from the chambers to the gas analysis devices is supplied by a discharge pump N86KN (KNF Neuberger GmbH, Germany) using a system of polyethylene

https://doi.org/10.17816/edgcc48700

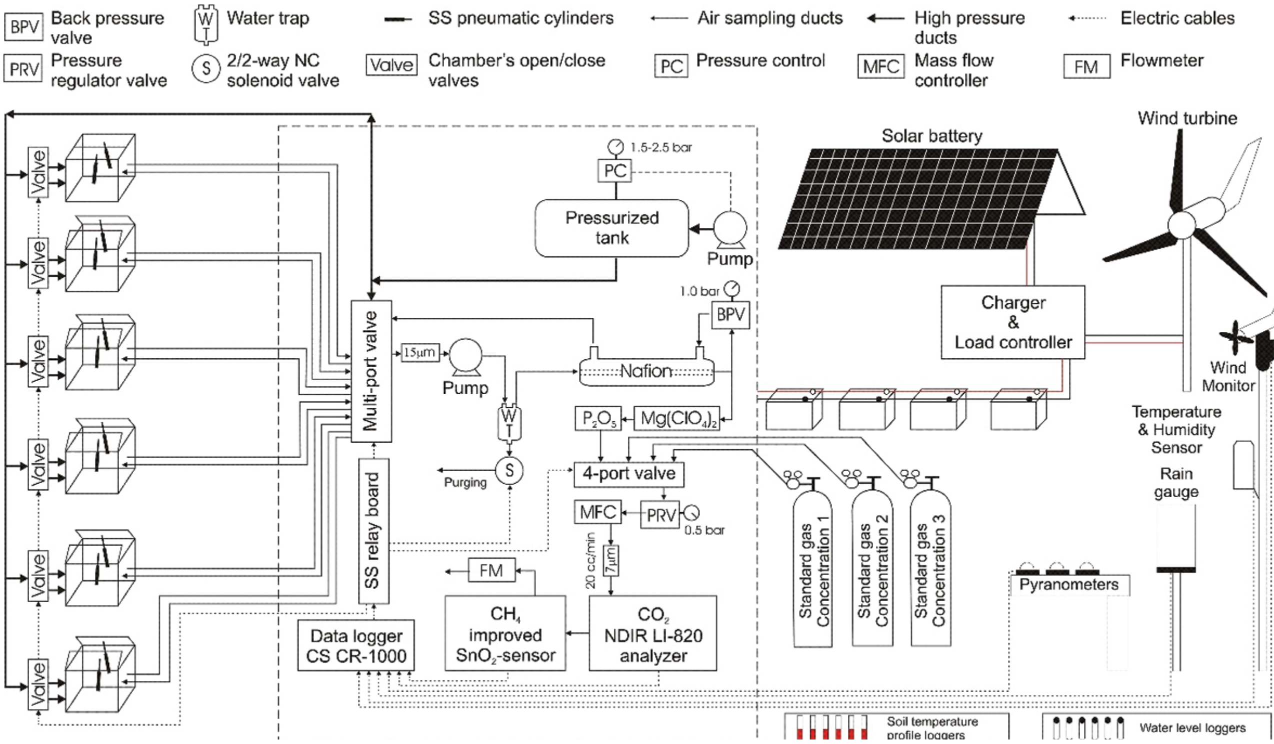


Fig. 1. The scheme of the automatic chamber system «Flux-NIES»

pipes (Ø 4 mm) and pneumatic electric valves. The CR1000 data logger (Campbell Sci., USA) is used to control the measuring system, collect and store information.

Much attention is paid to the preparation of the air sample during gas analysis: cleaning of solid aerosol fractions, dehumidification and stabilization of the flow and temperature in the devices. For this purpose, the "Flux-NIES" measuring complex includes in series (Fig. 1): fine filters (15 and 7 microns), pressure regulator (RPV), air sample flow regulator (MFC), condensate collection and discharge system (WT and S), nafion desiccant (Nafion), and final chemical powder desiccants ($Mg(ClO_4)_2$ и P_2O_5).

A set of rechargeable batteries is used for the autonomous operation of the complex as an uninterrupted source of electricity. The batteries are recharged during the day by solar electric panels or a wind turbine.

The main environmental parameters are monitored by: atmospheric pressure sensor RX2760 (OMEGA, USA); atmospheric temperature and relative humidity sensor HMP45A (VAISALA, Finland); wind speed/direction sensor 05103VM; precipitation sensor 52202H (R.M. Young Com., USA); pyrgeometer/radiometer PIR (Eppley Lab., USA); pyranometers of solar integrated radiation PCM-21 and photosynthetically active radiation PQS-1 (Kipp&zonen, the Netherlands). Additional measurements of soil temperature at depths of 5, 10, 20, 30, 40 cm are recorded separately by iButton DS1921G thermochronometric sensors (Maxim Integrated, USA), and the ground water level is measured by HOBO U20-001-04 sensors (Oneset Comp. USA) on various wetland areas.

The measurement method is based on recording changes in the studied gases concentration inside the chamber that is briefly isolated from the atmosphere (Fig. 1). The analyzed air is fed through the tubes through a controlled multi-way valve of the chamber selection. It is supplied to the input of the gas analysis unit at a speed of 3 l/min. The high-pressure valve (BPV) divides the air flow from the working chamber into two flows. The smaller one (20–30 ml/min) enters the gas-analyzers and is controlled by an air flow sensor (FM), and the remaining part returns to the chamber through the external circuit of the Nafion dehumidifier through the return pipe, thereby achieving a constant air pressure inside its insulated volume [Krasnov et al., 2013]. Taking into account that the maximum length of the tubes in the measuring system does not exceed 100 meters, the time air sample riches the gas analysis system is no more than 0.5 minutes.

In the normal state, all the chambers are open except for one (working), from which an air sample is taken. The order of chambers operation, the duration and time of their opening and closing are determined by the control program in the logger. Most commonly, the mode of five-minute exposure of the working chamber with a five-minute interval in its closed state was used.

The calibration procedure for standard gas mixtures is used twice a day to determine the sensitivity of the gas-analyzers in the FluxNIES measuring system. The CO_2 and CH_4 concentrations in three cylinders (in a neutral environment of pure synthetic air in atmospheric proportions) were selected in the following way: in the first case they obviously exceeded the highest concentrations of these gases achievable in working (closed) automatic chambers (and in different years were from 450 to 612 million^{-1} for CO_2 and from 5 to 10 million^{-1} for CH_4), in the second case, they were comparable to atmospheric background values and in the third case, they were very low (from 0 to 318 million^{-1} for for CO_2 and from 1.7 to 1.8 million^{-1} for CH_4). The current value of the calibration coefficient of the device *S(t)* (million^{-1}/mV) is determined by changing the signals of the gas-analyzers *dC (t)* depending on the known concentrations in the gas mixtures. The current value ideally should be constant. However, the analysis of calibration cycles (during the entire measurement period) showed that the obtained *S(t)* values for the used gas-analyzers are not constant and depend on external weather conditions, so the additional correction is required (for the CO_2 analyzer it is insignificant while the methane sensor needs it constantly).

A significant correlation of the signal with atmospheric pressure P (hPa) was found for NDIR $\mathbf{CO_2}$ gas-analyzer. CH_4 measurements are more affected by changes in the ambient temperature T (°C) and associated with it by the flow fluctuations of the air sample through the analyzed volume.

To reduce the variability of *S(t)*, the results of all measurements were adjusted with the found dependencies applying the following formulas:

$$\begin{aligned} S_{CO_2}(t_k) &= \Delta C_{CO_2}/(dC_{CO_2}(t_k) + K_{CO_2} \cdot (P_0 - P(tk))), \\ S_{CH_4}(t_k) &= \Delta C_{CH_4}/(dC_{CH_4}(t_k) + K_{CH_4} \cdot (T_0 - T(tk))), \end{aligned} \quad (1)$$

where t_k is the calibration time, ΔC_{CO_2} and ΔC_{CH_4} are the maximum concentration differences in standard gas mixtures (million^{-1}), $dC_{CO_2}(tk)$ and $dC_{CH_4}(tk)$ are the corresponding differences in gas-analyzer signals (mV), K_{CO_2} (mV/hPa) and K_{CH_4} (mV/°C) are the empirical coefficients, $P_0 = 1000$ hPa and $T_0 = 0$ °C are the primary pressure and ambient temperature.

The least square adjustment method with determining the linearity of the process by the pair correlation coefficient *R* was applied with the purpose of the most accurate determination of the gas fluxes value when processing changes in the output signals of the gas-analyzer $dC(t)/dt$ (mV/sec^{-1}) in the closed chamber mode. The width of the data filtering window was determined by the maximum value of R^2 which corresponded to the highest values of the detected emissions/runoff of the studied gases at the soil – atmosphere boundary. Since a 20 seconds averaging of the measurement data of the gas analysis instrument signals was used, the size of the filtration windows ranged from 2 to 4 minutes (or 6–12 reference points) due to the difference in the length of the air paths for the individual chambers of the system.

For the convenience of further data analysis in the measurement of gas fluxes, it is customary to switch to the weight characteristics (mg·m^{-2}·h^{-1}) which are calculated using the well-known formula [Ivanov et al., 2017]:

$$F(t) = S_n(t) \cdot dC(t)/dt \cdot 100 \cdot P/(273{,}15 + T) \times \times M/8312{,}6 \cdot V/S \cdot 3600, \quad (2)$$

where *Sn(t)* are the calibration coefficients of the device (see formula (1) above), *P* is the atmospheric pressure (hPa), *T* is the average air temperature during the chamber exposure (°C), *M* is the molar mass of the gas (g·mol^{-1}), 8312.6 is the universal gas constant (J·kmol^{-1}·K^{-1}), *V* and *S* are the volume and base area of the used chambers (m^3 and m^2, respectively), 3600 is the number of seconds per hour.

MEASURING STATION

The measurements were carried out at the "Plotnikovo" field station provided by the Institute of Soil Science and Agrochemistry SB RAS (ISSA, Novosibirsk, Russia) on the Bakchar bog in the Tomsk region during the warm season (from May to October). The measuring site marked with the letter "E" is located about 16 km from the settlement Plotnikovo in the Bakcharsky district [Maksyutov et al., 1999; Krasnov et al., 2013]. The site coordinates are 56°51' N, 82°51' E.

The satellite image and the automatic chambers configuration on the measuring platform are represented on figure 2.

Methane fluxes were determined by the means of the automatic method of closing dynamic chambers (non-steady-state through-flow systems) according to the ICOS recommendations [Pavelka et al., 2018]: six identical chambers made of transparent plexiglass (0.9·0.9·0.5 m^3) with pneumatically driven upper lids were installed on a moistened part of an open mesotrophic bog covered mainly with grass and moss. They were placed on different sections of the bog microrelief in such a way that the type of geological substate on each of them corresponded to a characteristic plant association.

The profile of observer points formed by the chambers is laid from the waterlogged wetlands to the pine-shrub-sphagnum phytocoenosis.

The first and second observation points correspond to the cotton grass-sphagnum phytocenosis.

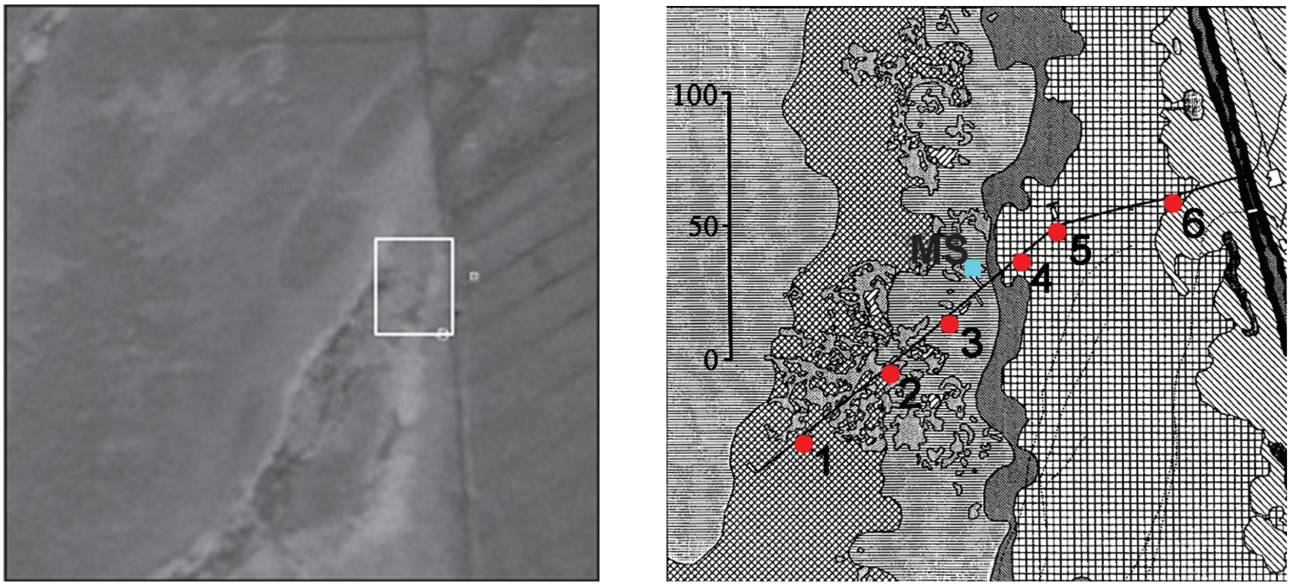


Fig. 2. Satellite image of the area and the layout of the automated system "Flux-NIES" on the bog site "E" according to [Maksyutov et al., 1999]. (•) the installation points of the measuring chambers and their numbers; (■) the location of the measuring station (MS) for gas analysis and registration of meteorological parameters

Chamber 1 is located at a certain elevation, the grass layer is represented by *vaginatum L.* – foliage cover (FC) is 50%, *Equisetum palustre* – foliage cover is 30%, *Carex limosa* – foliage cover is 5%, there are also single *Menyanthes trifoliata*. The moss cover consists mainly of *Sphagnum angustifolium* (FC 80%). Chamber 2 is characterized by a higher degree of water content, the herbaceous vegetation is represented by *Eriophorum vaginatum L.* (FC 50%), single specimens of *Menyanthes trifoliata*, *Carex limosa* and *Equisetum palustre*. The moss cover consists mainly of *S. cuspidatum* which foliage cover is 70%.

The third and fourth observation points are located in the sedge-sphagnum phytocenosis which vegetation cover consists of *Carex rostrate, Carex limosa* (FC 50%), there are single specimens of *Menyanthes trifoliata* and cranberry *Oxycoccus microcarpus Turcz*. In chambers 3, the moss cover is represented by *Sphagnum angustifolium* (FC 100%), in chamber 4 *S. angustifolium* and *S. pappilosum* are common (FC 80%).

Shrubs *Chamaedaphne calyculata* appear in the vegetation cover (FC 10%) closer to the forested part of the bog margin. Also there are single specimens of *Andromeda polifolia*, in the grass layer *Carex limosa* predominates (FC 40%) in combination with *Eriophorum vaginatum L.* (FC 20%). In the moss cover of chamber 5, *Sphagnum angustifolium* and *S. lindbergii* are found (FC 80%).

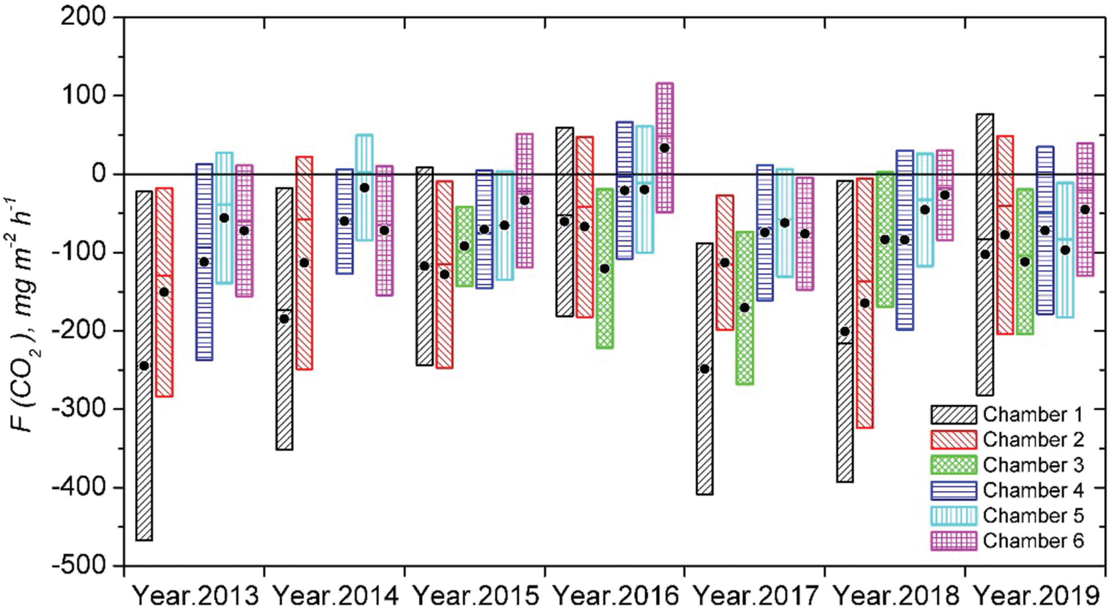
The sixth observation point is located in the pine-shrub-sphagnum phytocenosis. The tree layer is sparse and is represented by *Pinus silvestris f. Litwinowii* with a height of 2–3 m. In the shrub layer, *Chamaedaphne calyculata* dominates (FC 10%), there are single bushes of *Ledum palustre L.*, cranberry grows quite abundantly on tussocks (FC 15%), in the grass layer *Eriophorum vaginatum L.* prevails (FC 40%) and *Rubus chamaemorus* occurs (FC 3%). The moss cover in chamber 6 is mosaic represented by several species of sphagnum mosses (*Sphagnum fuscum, S. angustifolium, S. magellanicum*) with patches of green moss (*Polytrichum strictum*).

RESULTS AND DISCUSSION

Figure 3 represents the resulting gas fluxes at the soil – atmosphere boundary obtained during the measurement campaigns of recent years. The data analysis shows that the most dynamic CO_2 emission and uptake in the wetland plant associations were observed for chambers 1–3 which refer to the central section of the open bog. Smaller values of CO_2 fluxes were recorded at the edge of the bog in chambers 5 and 6.

The average seasonal uptake of CO_2 from the atmosphere varies significantly year by year both for individual plant associations and for the whole ecosystem. For example, the total CO_2 uptake to the bog surface in 2017 significantly exceeded the values observed in the 2016 measurement season (Figure 3, *a*).

The reasons for such variation in the absorption of atmospheric carbon by the bog surface lie in the weather conditions of a particular year of observation. Although bogs are difficult to consider



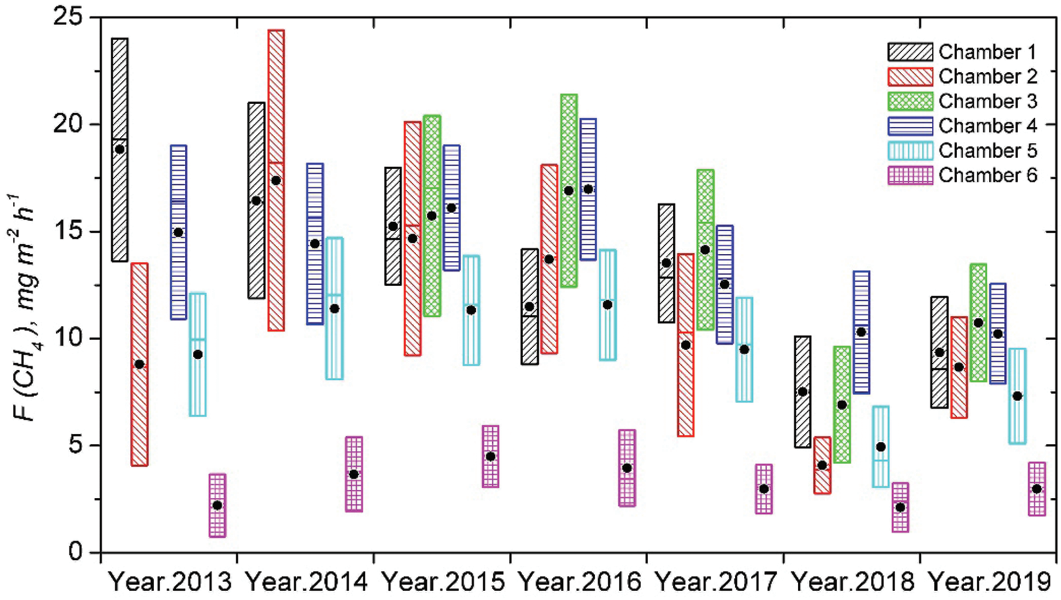


Fig. 3. Average seasonal (June-September) fluxes of CO_2 (*a*) and CH_4 (*b*) at the wetland soil – atmosphere boundary in the Bakchar bog in 2013–2019. (•) average daily values; (–) median daily values; (–) медианные суточные значения; (▌) areas of standart deviations

Table 1

Correlation data analysis and seasonal average values for wetland ecosystem moistening in 2014–2019

Years	2015	2016	2017	2018	2019	WL avg±STD, m	WL min, m	WL max, m	$T_{130\ cm}$ avg,°C
2014	0.570	0.369	***0.872***	0.688	***0.698***	–0.125±0.083	–0.252	0.054	+6.21
2015	1	–0,26	0.286	0.199	–0.06	–0.120±0.059	–0.261	–0.002	+6.88
2016		1	0.519	0.481	***0.752***	–0.166±0.068	–0.298	–0.052	+6.42
2017			1	0.690	***0.771***	–0.141±0.062	–0.263	–0.018	+6.92
2018				1	***0.803***	–0.038±0.042	–0.114	0.075	+5.96
2019					1	–0.132±0.083	–0.264	–0.004	+6.40

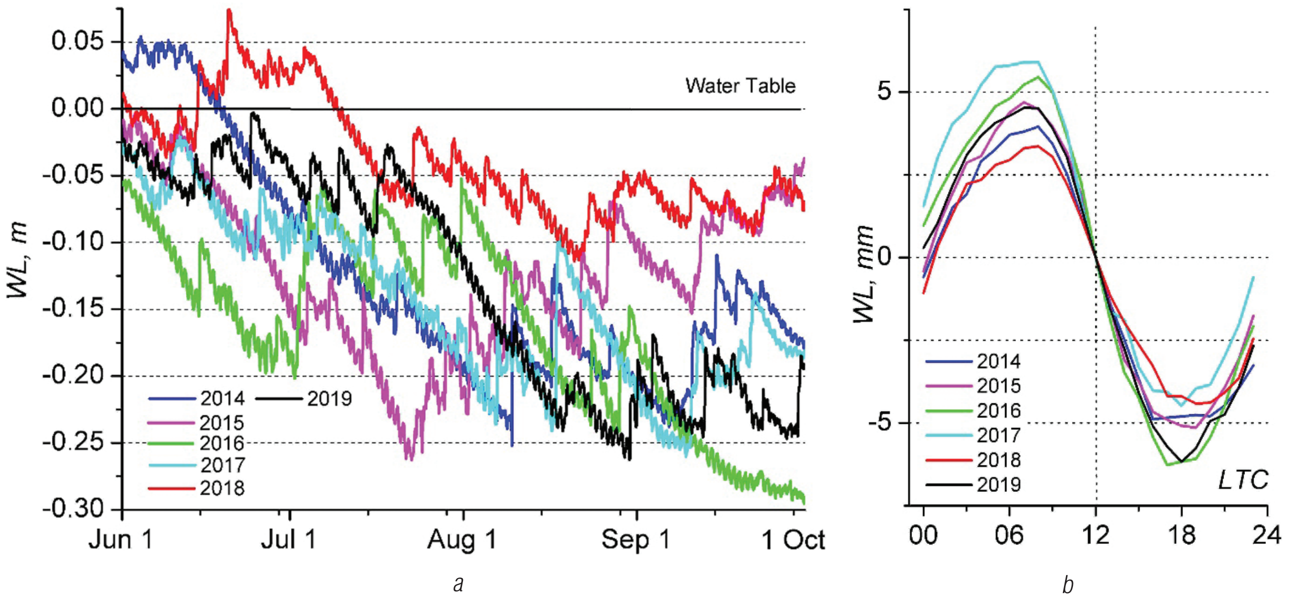


Fig. 4. Long-term seasonal dynamics of the soil water level (a) and its daily course (b) normalized to the average daily value and reduced to 12 hours of local time (LTC). (Bakchar bog, 2014–2019)

as drought-affected areas, seasons of low ground water levels are also observed here which affects the productivity of local plant associations.

Figure 4, *a* shows a record of long-term seasonal indicators of the water table level (WL) according to the HOBO U20-001-04 sensor installed in the center of the measuring platform "E" at a depth of 130 cm. A detailed inter-seasonal analysis of the WL data in Table 1 revealed a high significant correlation of the dynamics of soil waters in 2014 and 2017 when the most active CO_2 uptake was observed in bog ecosystems (Fig. 3, *a*).

However, the seasonal variation criterion of WL is not so reliable applying for average carbon exchange fluxes. For example, a correlation in the dynamics of soil waters over 2015 and 2019 was not found while the values of CO_2 uptake were similar. At the same time, in 2019, WL fluctuations showed an exceptional correlation with other measurement seasons which makes it considered a reference for this characteristic of the studied bog ecosystem (Table 1).

It is worth noting the presence of a stable diurnal course in WL (Fig. 4b) determined by the daytime evaporation from the peat beds and the night advection of water over the entire area of the bog [Eppinga et al., 2008]. For the decline in CO_2 uptake observed in wetland ecosystems in 2016, an increased evaporation of soil moisture was recorded compared to other seasons (Fig. 4, *b*).

The recorded interannual dynamics of methane fluxes in the studied ecosystem showed fairly stable values of CH_4 emissions in 2013–2017, and the total methane emission in the open fen (chambers 1–5) was significantly higher compared to the ryam section (Chamber 6). However, in the 2018 season, the CH_4 emission values showed an almost universal drop of 1.5–2 times (Fig. 3, *b*).

The reasons for such a critical change in gas exchange at the march ecosystem surface were associated with the observed abnormal amounts of precipitation and high WL values during the period when the processes of methanogenesis reached the seasonal maximum in late June and early July 2018 (Fig. 4, *a*). The influx of excess atmospheric moisture could cause the leaching and removal of the nutrient substrate necessary for the vital activity of methanogenic microorganisms outside the bog as well as disrupt the balance of biochemical processes which are significant in CH_4 oxidation in bog ecosystems [Kalyuzhny, 2018]. The daily course of WL in 2018 showed the smallest amplitude of oscillation (Fig. 4, *b*).

The influence of the 2018 weather anomaly on gas exchange in wetland ecosystems is discussed in detail in [Dyachkova et al., 2019].

The amount of gas fluxes in bog ecosystems is determined both by the level of soil water and by the seasonal behavior of such environmental characteristics as the insolation of the geological substate and the warming of the peat beds. The paper [Krasnov et al., 2015] provides detailed data on measuring the temperature of bog soil at different depths for two sections of the measuring site "E"at the Plotnikovo field station: with increased (chamber 2) and reduced (chamber 5) moisture content. Using the Fourier theory of thermal conductivity, the delay time of the heat pulse penetration in the peat layer was determined for the period of active development of methanogenesis processes in June 2014. Unfortunately, in this work, the fluxes of CH_4 were calculated using overestimated calibration coefficients (due to the output of the methane sensor characteristic in the region of nonlinearity), so that only a qualitative dependence of their value on the temperature of the peat beds warming on individual days of the measurement campaign can be traced.

On the other hand, the authors of paper [Veretennikova and Dyukarev, 2017] described in detail the relationship between the dynamics of methane emission and peat temperature for an open fen in another section of the Bakchar bog in 2013–2014 but obtained clearly underestimated median values of the daily CH_4 fluxes (less than 2 $mg \cdot m^{-2}/h^{-1}$). It should be noted that in this study, the method of portable static chambers was used for measurements which does not allow covering a sufficiently long time period.

In papers [Sabrekov et al., 2013; Glagolev et al., 2017], data from large-scale studies of CH_4 fluxes (using the same static chamber method) and the temperatures of the topsoil in the Bakchar bog in 2008, 2011 and 2015. In an open fen area comparable to the conditions for chambers 1–5 of the Flux-NIES measuring complex, the measured methane fluxes in July 2008 were 10.5–36 $mgS \cdot m^{-2} \cdot h^{-1}$ (or 14–48 $mg \cdot m^{-2} \cdot h^{-1}$). A dilute CH_4 emission with a median value of 0.3 $mgS \cdot m^{-2} \cdot h^{-1}$ (or 0.4 $mg \cdot m^{-2} \cdot h^{-1}$) was registered in August 2015 at the ryam site in a pine-shrub-sphagnum community (with Pinus sylvestris dominated in microrelief), comparable to the conditions for chamber 6 of the Flux-NIES measuring complex.

Finally, the authors of paper [Friborg et al., 2003] conducted studies of gas fluxes directly at the Plotnikovo field station by the method of turbulent pulsations (eddy covariance). Based on data from three measurement campaigns in May, July, and September 1999, the following seasonal average fluxes were obtained: –2247 $mg \cdot m^{-2} \cdot day^{-1}$ (or about -100 $mg \cdot m^{-2} \cdot h^{-1}$) for CO_2; 136 $mg \cdot m^{-2} \cdot day^{-1}$ (or ~$mg \cdot m^{-2} \cdot h^{-1}$) for CH_4. Comparing the different studies results of gases fluxes in this wetland ecosystem with two automatic methods, we get a good match if we take the microrelief between chambers 5 and 6 as the point of turbulent measurements (the so-called footprint).

CONCLUSIONS

The long-term applying of the automated chamber method has shown the effectiveness of its application for studying the dynamics of gas fluxes on the bog surface on a temporal and spatial scale.

The integral values of the CO_2 fluxes over the entire measurement period show that the surfaces of the West Siberian wetland are a powerful “absorbent” of atmospheric carbon. At the same time, the values of CH_4 emissions from different areas of the bog depend both on the type of vegetation and on the level of moisture and warming of the peat beds. The highest values of CH_4 emissions from wetland are observed in July and reach quite large values in open bogs (15–25 $mg \cdot m^{-2} \cdot h^{-1}$). The lowest values of CH_4 emission were observed in the ryam section (2–3 $mg \cdot m^{-2} \cdot h^{-1}$).

A significant decrease in values of CH_4 emission from the bog surface was observed in almost all measuring areas in 2018. This is linked to the observed weather anomalies during the period when the processes of methanogenesis reached their maximum seasonal values.

ACKNOWLEDGMENTS

The work was supported by the RFBR grant No. 18-45-700020 r_a. To implement the grant, the infrastructure of the IAO SB RAS was used, created and operated under the state assignment No. AAAAA17-117021310142-5, including the Research Equipment Sharing Center “Atmosphere”. The provision of field measurements was carried out with the participation of the Global Environment Research Foundation for National Institutes of the Environment Ministry of Japan.

The authors are grateful to E.A. Golovatskaya for providing a detailed description of the plant associations of the studied wetland ecosystem and to M.U. Arshinov for assistance in compilation a standardized block scheme of the measuring complex. The authors also thank A.A. Plotnikov for technical support for continuous measurements over many years.

REFERENCES

1. Белан Б.Д., Аршинов М.Ю., Козлов А.В., Давыдов Д.К., Ивлев Г.А. 2017. Автоматическая камера для измерения потоков парниковых газов на поверхности раздела почва-атмосфера // Патент на полезную модель № 169373. Правообладатель: ИОА СО РАН (RU).

2. Вадюнина А.Ф., Корчагина З.А. 1961. Методы определения физических свойств почв и грунтов в поле и лаборатории. М.: Высшая школа. 345 с.

3. Веретенникова Е.Э., Дюкарев Е.А. 2017. Суточные вариации эмиссии метана с поверхности болотных экосистем Западной Сибири в летний период // Метеорол. и гидрол. № 5. С. 69-79.

4. Глаголев М.В. 2010. Аннотированный список литературных источников по результатам измерений потоков CH_4 и CO_2 на болотах России // Динамика окружающей среды и глобальные изменения климата. Т. 1. № 2. DOI: 10.17816/edgcc121.

5. Глаголев М.В., Ильясов Д.В., Терентьева И.Е, Сабреков А.Ф., Краснов О.А. Максютов Ш.Ш. 2017. Потоки метана и диоксида углерода в заболоченных лесах южной и средней тайги Западной Сибири // Оптика атмосф. и океана. Т. 30. № 4. С. 301-309. DOI: 10.15372/AOO20170407.

6. Дьячкова А.В., Давыдов Д.К., Фофонов А.В., Краснов О.А., Головацкая Е.А., Симоненков Д.В., Nakayama T., Максютов Ш.Ш. 2019. Влияние аномальных факторов среды на эмиссию метана на Бакчарском болоте в районе п. Плотниково летом 2018 г. // Оптика атмосф. и океана. Т. 32. № 6. С. 482-489. DOI: 10.15372/AOO20190611.

7. Калюжный И.Л. 2018. Общие черты формирования гидрохимического режима основных типов болот России // Метеорол. и гидрол. № 8. С. 72-81.

8. Краснов О.А., Maksyutov S., Глаголев М.В., Катаев М.Ю., Inoue G., Надеев А.И., Шелевой В.Д. 2013. Автоматизированный комплекс «Flux-NIES» для измерения потоков метана и диоксида углерода // Оптика атмосф. и океана. Т. 26. № 12. С. 1090-1097.

9. Краснов О.А., Maksyutov S., Давыдов Д.К., Фофонов А.В., Глаголев М.В., Inoue G. 2015. Мониторинг эмиссии метана и двуокиси углерода из почвы в атмосферу и параметры почвы. Бакчарское болото Томской области (2014 г.) // Оптика атмосф. и океана. Т. 28. № 7. С. 644-654. DOI: 10.15372/AOO20150707.

10. Махныкина А.В., Прокушкин А.С., Ваганов Е.А., Верховец С.В., Рубцов А.В. 2016. Динамика потоков CO_2 с поверхности почвы в сосновых древостоях Средней Сибири // Журнал Сибирского федерального университета. Серия: Биология. Т. 3. № 9. С. 338-357.

11. Молчанов А.Г. 2017. Газообмен диоксида углерода с поверхности сфагнума в заболоченном сосняке южной тайги // Динамика окружающей среды и глобальные изменения климата. Т. 8. № 1. С. 43-54.

12. Ciais P., Sabine C., Bala G., Bopp L., Brovkin V., Canadell J., Chhabra A., DeFries R., Galloway J., Heimann M., Jones C., Quйгй C. Le, Myneni R.B., Piao S., Thornton P. 2013. Carbon and other biogeochemical cycles // Climate Change: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (570 pp.). Cambridge: Cambridge University Press. doi:10.1017/CBO9781107415324.015

13. Dyukarev E., Godovnikov E., Karpov D., Kurakov S., Lapshina E., Filippov I., Filippova N., Zarov E. 2019. Net ecosystem exchange, gross primary production and ecosystem respiration in ridge-hollow complex at Mukhrino bog // Geography Environment Sustainability. V. 12. N. 2. P. 227-244. DOI: 10.24057/2071-9388-2018-77.

14. Eppinga M.B., Rietkerk M., Borren W., Lapshina E.D., Bleuten W., Wassen M.J. 2008. Regular surface patterning of peatlands: Confronting theory with field data // Ecosystems. V. 11. P. 520-536. DOI: 10.1007/s10021-008-9138-z.

15. Friborg T., Soegaard H., Christensen T.R., Lloyd C.R., Panikov N.S. 2003. Siberian wetlands: Where a sink is a sourse // Geographysical Research Letters V. 30. N. 21. 2129. DOI: 10.1029/2003GL017797.

16. Ivanov D.G., Avilov V.K., Kurbatova Y.A. 2017. CO_2 fluxes at south taiga bog in the European part of Russia in summer // Contemporary Problems of Ecology. V. 10. N. 2. P. 97-104. DOI: 10.1134/s1995425517020056.

17. Maximov T.C., Dolman A.J., van Huissteden J., Ohta T., Sugimoto A., Maximov A.P., Kononov A.P., Petrov R.E., Ivanov B.I. 2012. Carbon budget in forest and tundra permafrost ecosystems of north-east Russia // Proceedings of the 5th International Workshop on C/H_2O/ Energy balance and climate over boreal and arctic regions with special emphasis on eastern Eurasia (11-13 November 2010, Wageningen, The Netherlands). Amsterdam. P. 21-24.

18. Maksyutov S., Inoue G., Sorokin M., Nakano T., Krasnov O., Kosykh N., Mironycheva-Tokareva N., Vasiliev S. 1999. Methane fluxes from wetland in West Siberia during April-October 1998 // Proc. Seventh Sympos. on the Joint Siberian Permafrost Studies between Japan and Russia in 1998. Tsukuba: Isebu. P. 115-124.

19. Nakano T., Inoue G., Maksyutov S., Sorokin M. 1999. Automatic measurements of methane flux in West Siberian wetlands in 1997 summer // Proceedings of the Seventh Symposium on the Joint Siberian Permafrost Studies between Japan and Russia in 1998. Tsukuba: Isebu. P. 211-215.

20. NOAA/ESRL. 2017. URL: https://www.esrl.noaa.gov/gmd/ccgg/trends/global.html (the date of access: 01.12.2020).

21. Suto H., Inoue G. 2010. A new portable instrument for in situ measurement of atmospheric methane mole fraction by applying an improved tin dioxide-base gas sensor // J. Atmos. Ocean. Technol. V. 27. P. 1175-1184.

22. Sabrekov A.F., Glagolev M.V., Kleptsova I.E., Machida T., Maksyutov S.S. 2013. Methane Emission from Mires of the West Siberian Taiga // Eurasian Soil Science. V. 46. No. 12. P. 1182–1193. DOI: 10.1134/S1064229314010098.

23. Pavelka M., Acosta M., Kiese R., Altimir N., Brьmmer C., Crill P., Darenova E., FuЯ R., Gielen B., Graf A., Klemedtsson L., Lohila A., Longdoz B., Lindroth A., Nilsson M., Jimйnez S.M., Merbold L., Montagnani L. Peichl M. Pihlatie M. Pumpanen J., Ortiz P.S., Silvennoinen H., Skiba U., Vestin P., Weslien P., Janous D., Kutsch W. 2018. Standardisation of chamber technique for CO_2, N_2O and CH_4 fluxes measurements from terrestrial ecosystems // Int. Agrophys. V. 32. P. 569-587. DOI: 10.1515/intag-2017-0045.

Received: 19.04.2021
Revised: 15.05.2021
Accepted: 20.06.2021

УДК 502.3 : 911.2 ; 379.85
DOI: https://doi.org/10.17816/edgcc50667

NATURAL FEATURES OF THE ORCHID REFUGIUM ON THE TERRITORY OF THE NATURAL PARK «SAMAROVSKY CHUGAS»

P.V. Bolshanik[1], *S.B. Kuznetsova*[1], *D.D. Karaseva*[1]

[1] Ugra State University, Khanty-Mansiysk, Russia

Corresponding author: P.V. Bolshanik, e-mail: bolschpetr@mail.ru

Citation: Bolshanik P.V., Kuznetsova S.B., Karaseva D.D. 2021. Natural features of the orchid refugium on the territory of the natural park "Samarovsky chugas»// Environmental dynamics and global climate change. V. 12. N 1. P. 15–26. DOI: https://doi.org/10.17816/edgcc50667

The article discusses the natural conditions and biological resources, landscape features of the key territory of the natural park "Samarovsky Chugas", located within the city of Khanty-Mansiysk. An overview of geographical studies of the natural park is given. The main components that influence the formation of natural complexes of a specially protected natural area are characterized. Special attention is paid to the characteristics of vegetation and the processes of anthropogenic changes in the landscapes of this key area. The main ways of vegetation transformation caused by economic activity and changes in the nature of surface runoff are highlighted. The ecological and geographical conditions of the orchid refugium are characterized. The article substantiates the need to allocate the study area as a zone with a protected regime within the territory of the natural park.

Keywords. Refugium, family *Orchidaceae*, flora, landscapes, specially protected natural areas, anthropogenic transformation of vegetation.

INTRODUCTION

The ecological situation in Ugra which is the main oil-producing region of Russia is characterized by a high level of anthropogenic and technogenic impact on the environment and low indicators of environmental health, as well as the intensive development of degradation processes of natural ecological systems. Khanty-Mansiysk is the capital of the Khanty-Mansiysk Autonomous Region, Ugra. A natural park "Samarovsky Chugas" is placed on its territory. The park is subjected to intensive residential and tourist-recreational impact. Therefore, the main purpose of the study was to identify areas with reserve status in relation to certain ecological and geographical niches (refugium) of orchid growth.

The species of the family *Orchidaceae* are both the most interesting and the most vulnerable part of the flora. Most orchids are rare species. The main reason for the decline in the population of species of the family *Orchidaceae* on the territory of the Khanty-Mansiysk Autonomous Region is the fact of growing industrial development primarily associated with oil and gas production, the development of local infrastructure and the rapid population growth of cities and settlements in the region. It causes changes in natural biocenoses which can lead to a decrease in the resistance of rare species. Therefore, the issues of searching for new habitats, assessing the stability of populations and identifying factors that limit them in the conditions of the northern regions are relevant [Shepeleva L.F., Lukyanenko D.N., 2009].

Most of the species of the family *Orchidaceae* in Russia are rare species that require protection. 25 species from 16 genera of the family *Orchidaceae* grow on the territory of the Khanty-Mansiysk Autonomous Region. Of these, 18 species (72.2%) are listed in the Red List of Threatened Species of the Khanty-Mansiysk Autonomous Region, 7 species (10.6%) in the Red List of Threatened Species of the Russian Federation (RF) [Determinant, 2006; Red Book, 2013; Red Book, 2008].

The nature Park "Samarovsky Chugas" is located on the territories of the municipal settlements: Khanty-Mansiysk region and the city of Khanty-Mansiysk. The following 6 species of the Orchid family were noted previously on the "Samarovsky Chugas" territory: *Goodyera repens* (L.) R.Br., *Dactylorhiza hebridensis* (Billmot) Aver, *Cypripedium guttatum* Sw., *Coeloglossum viride* (L.) C. Hartm., *Herminium monorchis* (L.) R. Br., *Mycrostylis monophyllos* (L.) Lindley [Chronicle, 2017]. Of these, 4 species are listed in the Red List of Threatened Species of the Khanty-Mansiysk Autonomous Region: *Cypripedium guttatum* Sw., *Coeloglossum viride* (L.) C. Hartm., *Herminium monorchis* (L.) R. Br., *Mycrostylis monophyllos* (L). Lindley.

Cypripedium guttatum Sw., Coeloglossum viride (L.) C. Hartm., Mycrostylis monophyllos (L.) Lindley are classified in category 3 (rare species) of the rarity scale in the Red List of Threatened Species (RF). Herminium monorchis (L.) R. Br. is classified in category 0 (probably disappeared species but the possibility of their preservation cannot be excluded) [Determinant, 2006].

A decrease in the populations of species of the family *Orchidaceae* is observed both on the whole region territory and in particular on the territory of the natural park. Commonly, the general environmental resistances in this region for these representatives of the family *Orchidaceae* are the following: low competitive ability, small populations, weak renewal by seed, habitat disturbance due to increased anthropogenic load (logging, fires, deer grazing, soil reclamation and peat harvests, recreation, collecting for bunches and for medicinal purposes, digging for the purpose of introduction [Determinant, 2006; Red List, 2013; Red List, 2008]. On the Ugra territory we have insufficient information about the distribution of representatives of the family *Orchidaceae*. The occurrence of different species of orchids was evaluated in the territories of the reserve "Malaya Sosva", the natural park "Kondinsky Lakes" of the Sovetsky region, the reserve "Yugansky" in the Surgut region and in the interstream area between 2 rivers: the Big Salym and the Irtysh.

As a rule, the general environmental resistances in this region for these representatives of the Orchid family are the following: low competitive ability, small populations and habitat disturbance due to increased anthropogenic pressure (logging, fires, deer grazing, recreation).

An accessory factor for specie *Cypripedium guttatum* Sw. is collection for bouquets and for medical purposes, digging for the purpose of introduction and weak seed regeneration.

The environmental resistance for *Mycrostylis monophyllos* (L.) Lindley is economic development of the territory, soil reclamation and peat harvests [Red List, 2013].

The search for new habitats, description of physical and geographical conditions of growth, and identification of the environmental resistances for the representatives of the family *Orchidaceae* in the northern regions are very relevant and therefore presented as the objectives of our research.

MATERIALS AND METHODS

The research area (Fig. 1) is located to the north-east of a residential part of the city Khanty-Mansiysk and south-west of the international airport and is part of the natural park "Samarovsky Chugas". The north-western border of the site is a Bypass Road (azimuth 247°), the north-eastern border is a bicycle path (azimuth 336°), the south – eastern border is the highway "Khanty-Mansiysk – Surgut" (azimuth 57°), the south-western border is the land – use territory of the Ugra Research Institute of Information Technologies (azimuth 152°). The configuration of the study area resembles a trapezoid elongated in a north-easterly direction. The study area is 10.23 hectares. Coordinates of the extreme points of the area: northwest corner – 61°01 '18,4206" and 69°05'09,3148", northeast corner – 61°01 '21,1525" and 69°05'34,9610", southeast corner – 61°01'10,3365" and 69°05'18,0438", southwest corner – 61°01'16,5119"and 69°05'38,3599".

The researches were aimed at studying the floral richness of the site, laying reconnaissance routes with photographing flora species, conducting geobotanical and geomorphological profiles, describing characteristic landscapes, performing landscape mapping, and characterizing the relief of the key site.

The survey of the territory was carried out by the route – eye sketching method. Stations with a complete geobotanical reference description were made every 250 meters. Geobotanical profiles with a width of 5 m were laid at the intersection of the terrain. On the territory of the key site, 4 profiles were laid and 18 descriptions of plant communities were made.

The ontogenetic states of the representatives of the family *Orchidaceae* were identified according to standard methods (Plant coenopopulations, 1988), taking into account the peculiarities of the description of the orchids ontogenesis (Vakhrameeva et al., 1991). In population-ontogenetic studies, an bion is accepted as a counting unit of orchids with a stem-rooted tuberoid, and for rhizomatous species – a partial shoot (Plant Cenopopulations, 1988). The age structure of species populations of the family *Orchidaceae* has not been studied in detail. The bions of the generative and pregenerative states were counted.

The origin of a natural park and the study of its natural conditions and resources

In order to preserve the unique natural complexes and in accordance with the Federal Law "On Specially Protected Natural Territories", Order No. 375 of the Presidium of the Government of the Khanty-Mansiysk Region of October 17, 2000, the establishment of the "Khanty-Mansiysk Hills" Nature Park is being created. In January 2001, the Park acquired the status of a state institution and its final name-the Nature Park of regional significance "Samarovsky Chugas". In March 2013, the decree of the Government of the Khanty-Mansiysk Autonomous Region – Ugra No. 65 approved the title document "On the formation of the natural park "Samarovsky Chugas".

The following organizations took part in the development of the natural park project:

DOI: https://doi.org/10.17816/edgcc50667

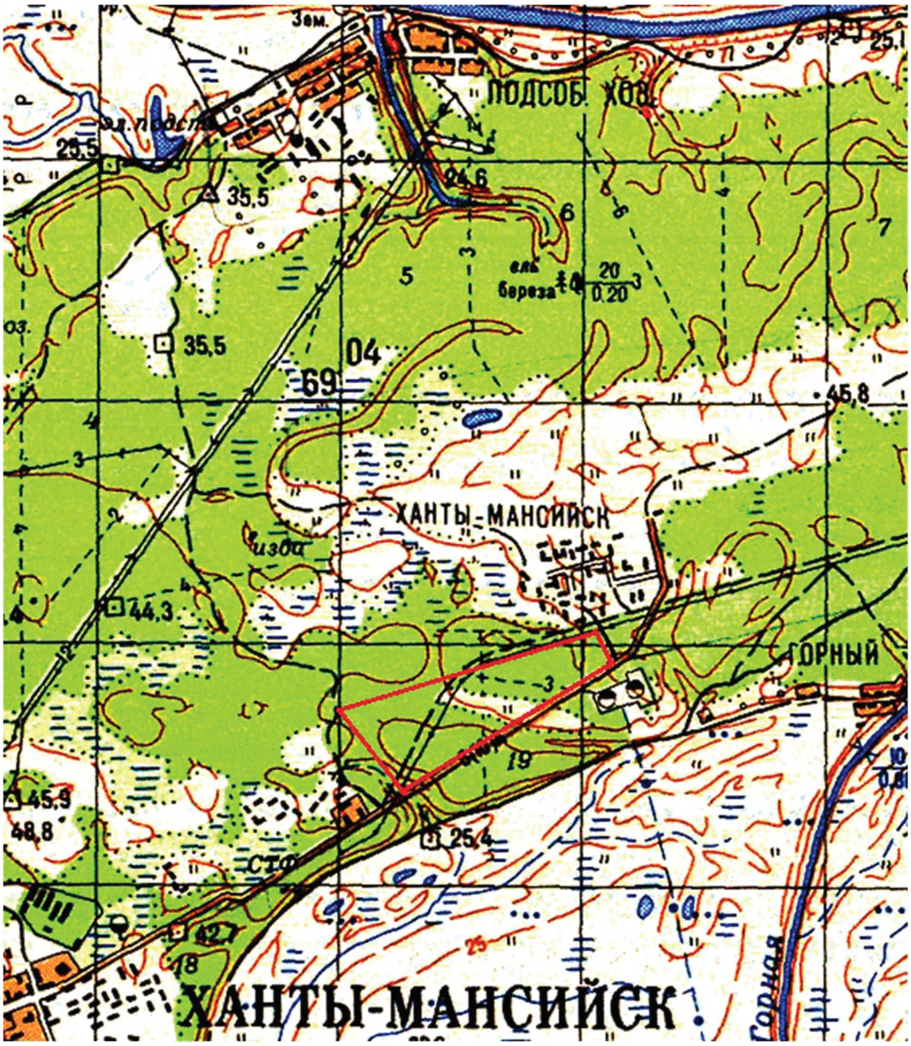


Fig. 1. Geographical location of the researched area

Zapsiblesproekt (General Contractor), the West Siberian State Unitary Forest Management Enterprise, the West Siberian Branch of the Federal State Budgetary Scientific Institution "All-Russian Research Institute of Hunting and Animal Husbandry named after professor B.M. Zhitkov", the Ural State Forestry University, the Institute of Soil Science and Agrochemistry of the Siberian Branch of the Russian Academy of Sciences, the Central Siberian Botanical Garden of the Siberian Branch of the Russian Academy of Sciences, the Tyumen Forest Experimental Station of the All-Russian Research Institute of Forestry and Forestry Mechanization.

The nature in the park's territory has been studied by many authors. The geological structure and relief of the Khanty-Mansiysk territory was considered in the joint monograph [Volkov I.A., Volkova V.S., Gurtovaya E.E., 1973]. In this monograph the question of the upland origin was raised for the first time. Subsequent works consider two hypotheses of the upland origin – tectonic and glacial [Krapivnera R.B., 1979]. Further geological and geomorphological studies were supplemented by drilling data which indicate that both alluvial and glacial deposits are found in the thickness of the upland rocks [Report, 1985]. The detailed origin of the erosional outlier and the influence of exogenous geological processes on it are considered in a number of works [Kuskovsky V.S., 2002; Bolshanik P.V., 2017]. The climatic parameters of the studied area were characterized on the basis of data from the Khanty-Mansiysk weather station and summarized according to the explanatory note to the Atlas of the Khanty-Mansiysk Autonomous Region – Ugra [Atlas, 2004]. The characteristics of the soil and vegetation cover and the animal world were studied on the territory of the natural park "Samarovsky Chugas", as well as on the territory of other protected areas of the region [Antipov A.M., 2001; Baykalova A.S., Zvyagina E.A., 2020].

DOI: https://doi.org/10.17816/edgcc50667

CHARACTERISTICS OF NATURAL RECREATIONAL RESOURCES

Geological aspects and relief

The formation of the recent relief occurred in the Late Quaternary and was caused by the development of lateral erosion of water flows and permafrost processes. Numerous rivers meandered through the low-lying plains and thus vast alluvial surfaces were formed. The age of these plains (modern above-floodplain terraces) including the subglacial plain is 13–20 thousand years [Volkov I.A., Volkova V.S., Gurtovaya E.E., 1973].

The recent rivers floodplains were formed in the Holocene. These floodplains have a significant width in conditions of flat terrain and small elevation differences, although they are inferior to the alluvial plains of the Pleistocene.

The flat part of the “Samarovsky Chugas” belongs to the three above-floodplain terraces of the Ob River. The relative height of the third above-floodplain terrace is 45–60 m, the first-up to 25 m [Kuskovsky V.S., 2002].

The relief of the research area is represented by the hollow-arching surface of the second above-floodplain terrace between the Ob and Irtysh rivers. The terrace is erosive and accumulative located at altitudes from 33 to 45 m. The terrace is composed mainly of sandy loam with a thickness of more than 3 meters. Also, it has sandy clay lenses and fine-grained sand, the alternation of which gives the profile a layered appearance. The terrace surface is cut through by the valley of a temporary stream. The above-floodplain terraces have the ridge-and-kettle mesorelief creating a variety of vegetation and soil cover.

After the Bypass Road construction in 2004, the conditions of land runoff changed and a pond with a small island was formed in a valley of the small stream (Fig. 2). An anthropogenic element of the terrain is the embankment of the Bypass road and the drainage ditch with depth of 2 m running along it.

Climate and hydrography

The climate of the researched area reflects the main patterns of climate formation in the Khanty-Mansiysk Autonomous Region – Ugra. It is correct to use data from long-term observations of the meteorological observing station of Khanty-Mansiysk to characterize the bioclimatic resources of researched area due to its location and small area.

Fig. 2. The pond within the key area

DOI: https://doi.org/10.17816/edgcc50667

The temperature behavior. In general terms, a temperature regime of any territory is determined by the amount of incoming solar radiation and its further distribution.

The thermal-energy resources of the Natural Park territory include the following indicators. The average annual air temperature is –1.1°C. The winter months are characterized by stable low temperatures. The coldest month is January with an average temperature of –19.8°C (Table 1).

These data allow us to characterize the bioclimatic resources of the Natural Park area as insufficiently provided with heat, with very cold and severe winter and cold summer. Uncomfortable conditions during winter months are primarily associated with severe hypothermia for all biological objects. The thermal conditions during summer season indicate a short growing season.

Humidification conditions. Atmospheric precipitation is the main source of moisture for the territory of the natural park «Samarovsky Chugas». The average annual precipitation is 494 mm (Table 2). The humidity factor (according to N.N. Ivanov) is 1.2, therefore, the moisture conditions can be characterized as excessively wet.

The seasonal distribution of precipitation is uneven. The maximum precipitation amount is recorded during period from April to October (75–83%), especially in July and August. In winter, the amount of precipitation is 17–20% of the annual amount due to the beginning of an anticyclonic climate regime and period of low temperatures. Thus, maximum precipitation amount for the growing season (from May to September) is up to two-thirds of the annual precipitation. The autumn transition of the daily average temperature through 0°C is timed to the first decade of October. At the same time, the formation of snow cover begins. A stable snowpack is formed by November. It reaches its maximum depth in March. At this time, its average height is 57 cm, the maximum height is 90 cm [Atlas, 2004]. Based on all of the above, the study area can be attributed to the zone of excessive moisture and insufficient heat supply.

The most important bioclimatic indexes from an ecological point of view are shown in table 3.

After the construction of highway and access roads to it which go from the airport to Khanty-Mansiysk, an increase in flooding of landscapes is recorded. It often leads to the death of stands from rising ground water levels. The bypass road is an extended low-pressure dam (barrage) at the landscape. The micro landscapes which are both intensively flooded and intensively drained are formed along the road despite being equipped with culverts. On soils with permafrost, the situation is aggravated by thermokarst processes. An example of such flooding in the study area is the formation of a pond in the drain hollow and a swamp in the flat-curved water-collecting top of the valley of a small watercourse.

Soils

The parent rocks on the territory of the Natural Park “Samarovsky Chugas” are Upper Quaternary covering small-depth sandy loams, underlain by sand or buried moraine. Another type of parent rocks at this territory are alluvial layered sandy deposits [Krapivnera R.B., 1979].

The formation of the upper layer of Quaternary sediments on the Khanty-Mansiysk Autonomous Region territory is associated with the underground glacial lake existence at this territory during the Upper Pleistocene. Here, the absolute water marks reach about 120 m. After the disappearance of the lake, four glaciolacustrine terraces were formed with absolute marks of the rear seam of 120, 80, 60 and 40 m. After the lake descent, the formation stage of the valleys of recent rivers began (9–8 thousand years ago) [Volkov I.A., Volkova V.S., Gurtovaya E.E., 1973].

Table 1

The air temperature, °C (according to data from the Khanty-Mansiysk meteorological observing station)

Monthly mean						Annual mean	Duration of period with daily average temperature ≤ 0°C, days	Duration of period with daily average temperature ≤ 10°C, days
I	V	VI	VII	IX	X			
-19.8	6.6	14.3	17.5	8.4	-0.7	+1.4	187	98

Table 2

Average monthly and annual precipitation amounts (mm) (according to data from the Khanty-Mansiysk meteorological observing station)

Monthly mean						Annual mean
I	V	VI	VII	IX	X	
23	48	55	67	54	48	494

Table 3

The main climate indexes of the territory of Natural park "Samarovsky Chugas" according to data from the Khanty-Mansiysk meteorological observing station)

Climatic indexes	
1. Yearly average temperature, ˚C	–1.4
2. Average yearly precipitation amount, mm	494
3. Thermoenergetic resources per year, kcal/cm^2	30
4. The summery of internal equivalent for growth temperatures, ˚C	1400
5. The average of growing season duration, days	98
6. Average yearly humidity factor (according to N.N. Ivanov)	1.2

In general, there are flattened and drained watershed divides in the study area. This contributes to the formation of both automorphic soils and soils with varying degrees of hydromorphism.

The soil cover is characterized by a great variety and noticeable mosaic which reflects the result of the interaction of bioclimatic and lithological-geomorphological conditions.

On the riverine parts of basin divides, ridge tops, kettle backs and ancient terraces where ground-water table is deep, under dark coniferous and light coniferous plantations with moss and moss-shrub ground cover, soil formation is of the podzolic type. However, the extent of the podzol formation process is not the same. It is determined by the water permeability of the soil layer which depends mainly on the mechanical composition of the parent rocks [Atlas, 2004].

Podzolic soils are the predominant on the territory of the natural park and are formed on elevated well-drained features with deep ground-water table, under a dark coniferous forest. The process of podzol formation is less prominent at the territories where parent rocks are characterized by reduced water permeability. The soil cover is represented by podzolic gleic soils with signs of shallow, intra-profile and deep gley.

The waterlogging appears on poorly drained central parts of flat watershed divides, ancient terraces and on smooth hillsides which means in locations where weakened surface water flow is characteristic. The excessive moistening contributes to the occurrence of the marsh process and the formation of swampy-podzolic soils.

In depressions across the ridges and closed basins, ground waters which table is shallow has a certain influence on soil formation. This enhances the development of the marsh process of soil formation regardless of lithology of the rocks on which marsh soils are formed.

Thus, two main soil processes can be distinguished at the research area: podzolic and bogginess, which determine the development of automorphic, semi-hydromorphic and hydromorphic soils.

RESULTS

Flora of the researched area. Anthropogenic influence

The bioclimatic conditions of pedogenic process which are characteristic of the middle taiga are aggravated by the "warming" influence of the floodplain ecosystems of the Ob and Irtysh. As a result, fir, mountain ash, juniper, elderberry which are characteristic of the subzone of the southern taiga, are found in the vegetation. The appearance of sod-podzolic soils in the soil cover is also associated with the nature of the vegetation cover (increased ash content of litter).

On the basis of the conjugate analysis of soil, geobotanical and forest taxing data on the interrelation between forest types and soils the forest-growing characteristics of soils were given (Table 4).

Distribution. On the territory of the natural park «Samarovsky Chugas» *Goodyera repens (L.) R.Br.* grows in dark coniferous forests (rarely), *Cypripedium guttatum Sw.* grows in mixed and deciduous forests (rarely), *Coeloglossum viride (L.) C. Hartm.* pedogenic in dark coniferous forests and near streams (rarely). The locations of *Herminium monorchis (L.) R. Br.* and *Mycrostylis monophyllos (L.) Lindley* require confirmation [Shepeleva L.F., Lukyanenko D.N., 2009].

Dactylorhiza hebridensis is common in dark coniferous forests. However, our observations show that this species is represented by small isolated populations. In the forests within the city of Khanty-Mansiysk, the number of locations of this species is decreasing.

On the territory of the key site, we found a large population of *Dactylorhiza hebridensis* (Table 5). It is located in two habitats (Table 6). The first is confined to a drainage ditch running along the bypass road. 307 plants of *Dactylorhiza hebridensis*

Table 4

The interrelation of forest types and soils at the key area

Type of forest	Soils	Location	Type of moisturizing
Pine, birch and ledum- clusterberry forests	Podzolic typical gley illuvial ferruginous	The underneath parts of the slopes of drained watersheds on sandy rocks	Hydromorphic
Dwarf pine, spruce and fir forests with green mosses and berrying ground	Podzolic	The elevated sites of watersheds, tops of ridge-shaped hump of floodplain terraces on sandy rocks	Automorphic semihydromorphic
Dwarf pine, spruce and fir forests with green mosses and small grasses	Podzolic alpha-gley soil illuvial ferruginous	The elevated parts of watersheds and floodplain terraces on sandy loam rocks	Semihydromorphic

were found on this territory. The plants are concentrated in three groups (the total length of this habitat is 1087 meters long, 3 to 6 meters wide). The extreme eastern point of this habitat has coordinates 61°01’19,9924’’ N and 69°05’24,9961’’ E, the extreme western point has coordinates 61001’14.9400” N and 69004 ‘35.7893” E. The population of *Dactylorhiza hebridensis* (Fig. 3) is mixed with the population of *Dactylorhiza incarnata* (Fig. 4). In total about 10 of them were found.

The second habitat is located under the canopy of coniferous forest with an admixture of parvifoliate species. The forest grows on the hollow-bored basin of the drainage funnel lying in the upper reaches of the drain valley. The *Dactylorhiza hebridensis* and the *Corallorhiza trifida* can be found. The coordinates are the following: 61°01’14,5283’’ N and 69°05’30,0172’’ E (Fig. 5).

Outside the key area but within the boundaries of the natural park, there is another orchid habitat (coordinates: 61°01’14,5283’’ N and 69°05’30,0172’’ E) with similar physical and geographical conditions. It is characterized by the following rare and protected plants: *Dactylorhiza hebridensis* — 50 plants and *Anemone nemorosa* — 9 plants (Fig. 6).

A separate habitat is formed by the cenopopulations of *Dactylorhiza hebridensis* and *Dactylorhiza incarnata* located at a distance from the borders of the natural park (coordinates: 61°00’47,7282’’ N and 68°59’50,2049’’ E). However, similar features of physical and geographical conditions are characteristic of this site. On the one hand, the area is protected by the embankment of the bypass road, from which there is additional runoff moisture. On the other hand, the forest wall is a protective barrier. All areas are well illuminated by the sun in the evening and there is a reservoir nearby.

Fig. 3. *Dactylorhíza maculáta*

Fig. 4. *Dactylorhiza incarnata*

Fig. 5. *Corallorhíza trífida*

DOI: https://doi.org/10.17816/edgcc50667

Fig. 6. *Anemone sylvestris* L.

The geography of protected plants distribution on the territory of the key site is shown in Fig. 7.

The fauna of the key area is represented by ducks living in the pond (*Bucephala clangula* and *Aythya fuligula*) [Antipov A.M., 2001] and forest mammals (*Sciurus vulgaris*, *Tamias sibiricus*).

The anthropogenic impact on the site is manifested in winter due to the clearing of the bike path, when part of the snow is raked into the pond.It is necessary to install a barrier on the second side of the bike path to eliminate the negative impact of melted snow on the site vegetation. It will also serve as additional protection from erosion processes. The slope of the bypass road in the pond area exceeds 45°. In the summer, grass is mowed in the drainage ditch which can also affect the number of orchids.

The anthropogenic impact considered in this paper as an exogenous geological factor acts in relation to the flora in a similar way to other natural conditions. Human impact leads to the formation of new habitats in which some plant species find refuge, while others become extinct. Drainage ditches have become such habitats on the territory of the natural park: the ditches play the key role in microclimatic and hydrological conditions favorable for the growth and development of orchids.

CONCLUSION

A disturbed ecotope was found on the territory of the "Samarovsky Chugas" where representatives of the *Orchidaceae* family grow. This ecotope is formed by a drainage ditch along the Bypass Road. The growth of *D. incarnata* and *D. hebridensis* in this location is facilitated by the absence of species competition, favorable microclimatic and hydrological conditions. The ability of these species to populate anthropogenically altered landscapes should be considered as a manifestation of the explerent component of the ecological and phytocenotic strategy. Data on the growth of representatives of the *Orchidaceae* family in technogenically altered ecotopes present in different regions of Russia. It is proposed to consider such places as refugiums for rare plant species (Egorova, 2018; Mishagina, 2018).

Thus, the anthropogenic impact on landscapes is manifested both in negative features (the extinction or decrease in the number of species) and in the creation of new habitats that are shelters for rare plants (positive features).

Fig. 7. The location of rare plants within the researched area on the aerial photograph (red stars — *Corallorhíza trífida*, orange stars — *Dactylorhíza maculáta*, yellow stars — *Dactylorhiza incarnata*, white star — *Cotoneaster melanocarpus*)

DOI: https://doi.org/10.17816/edgcc50667

Table 5

Rare species of orchids at the researched areas

Title	Status	Ecology and biology aspects	Limiting factors	Protection measures	Location in the researched area
Dactylorhiza incarnata (L.) Soó	The third category. Rare species. It is included in Annex II of the International Convention CITES	Meadow-bog species. On the Ugra territory, it grows on sedge and moss lowland and transitional bogs, sedge and buck-bean hypnaceous bogs; once it was found on a sandy fill overgrown with willow. Seed reproduction. Blooms in June – July.	The ecological amplitude narrowness of the species, the violation of natural habitats during the economic development of the territory.	It is necessary to identify new habitats, monitoring the populations status	It occurs along the northern border of the key site with three isolated cenopopulation locuses. The total quantity is about 10.
Dactylorhiza hebridensis (Wilmott) Aver.	The fourth category. The species with undefined status. It is included in Annex II of the International Convention CITES	Meadow-bog species. Distributed mainly in wet and boggy meadows, transitional and low-lying bogs, on the outskirts of sphagnum bogs, in boggy coniferous and deciduous forests, thickets of shrubs, sometimes along the banks of reservoirs, along streams, along river valleys as well as in anthropogenic disturbed habitats – on overgrown cuttings, roadsides, etc. It is propagated mainly by seeds. Blooms in late June – July.	The violation of natural habitats during the economic development of the territory, marshland reclamation, low competitive ability.	It is necessary to identify new habitats, specifying the location of population and monitoring the populations status	It occurs along the northern border of the key area as a continuous strip with small breakages, along the drainage ditch along the bypass road. The total number of discovered plants is about 300
Corallorhiza trifida Chatel	The second category. The species which is declining in number. It is found in the natural park "Numto" in Ugra.	A perennial herbaceous plant devoid of chlorophyll (saprotroph). It blooms in late May-June, bears fruit in August. Often, it leads an underground lifestyle for several years. It grows in damp forests, meadows, bogs, among shrubs, on open peatlands. It prefers well-moistened areas, it is not very demanding to the high fertility of the soil and its reaction	It suffers the most from deforestation, drainage of waterlogged habitats as well as trampling down of growing areas.	Included in Annex II to the CITES Convention	It was found in the amount of 4 specimens in the catchment basin of the upper reaches small watercourse valley

DOI: https://doi.org/10.17816/edgcc50667

Table 6

MOrchid habitats in the studied areas

The habitat and the coordinates	The type of phytocenosis and its species composition	Biotic and abiotic conditions and anthropogenic impact	Species composition of orchids	The number of each species in a given habitat
The western flat slope of the drainage ditch, from the point with coordinates 61^{0}01’19,9924’’N and 69^{0}05’24,9961’’ E to the point with coordinates 61^{0}01’14,9400’’ N and 69^{0}04’35,7893’’ E	A motley grass-grasses association of technogenically altered landscape. (*Calamagrostis epigeios* (L.) Roth, *Equisetum arvense* L. , *Chamaenerion angustifolium* (L.) Scop., *Equisetum sylvaticum* L., *Hieracium umbellatum* L., *Trifolium pratense* L., *Calamagrostis langsdorffii* (Link) Trin., *Agrostis gigantea* Roth ,*Poa angustifolia* L. , *Elytrigia repens* (L.) Nevski, *Poa palustris* L., *Bromopsis inermis* (Leyss.) Holub, *Phleum pratense* L., *Poa pratensis* L., *Crepis tectorum* L., *Rubus idaeus* L., *Festuca pratensis* Huds., *Artemisia vulgaris* L.).	periodic haymaking and snow dumping when cleaning the sidewalk	*D. hebridensis* (Wilmott) Aver *D. incarnata (L.) Soo.*	307 units 10 units
The western hollow-bored slope of the drainage funnel lying in the upper reaches of the drainage valley with coordinates 61^{0}01’14,5283’’N and 69^{0}05’30,01’’ E	Fir-spruce-birch dwarf pine with blueberries and green mosses; in the grass-shrub layer the most represented are the following species: *Vaccinium myrtillus* L., *Oxalis acetosella* , *Maianthemum bifolium* (L.) F.W.Schmidt, *Pyrola rotundifolia* L., *Vaccinium vitis-idaea* L., *Gymnocarpium dryopteris* (L.) Newn, *Linnaea borealis* L. В редком подлеске *Sorbus sibirica* Hedl., *Rosa majalis* Herrm., *Sambucus sibirica* Nakai.).	no anthropogenic impact	*D. hebridensis* (Wilmott) Aver *C. trifida* Chatel.	28 units 4 units
The western flat slope to the ditch with coordinates 61^{0}01’14,5283’’N and 69^{0}05’30,0172’’ E	A motley grass-grasses association of technogenically altered landscape. (*Calamagrostis epigeios* (L.) Roth, *Equisetum arvense* L., *Equisetum sylvaticum* L., *Hieracium umbellatum* L., *Tussilago farfara* L., *Trifolium repens* L., *Poa angustifolia* L., *Elytrigia repens* (L.) Nevski, *Poa palustris* L., *Bromopsis inermis* (Leyss.) Holub, *Poa pratensis* L., *Crepis tectorum* L., *Festuca pratensis* Huds., *Geum aleppicum* Jacq., *Prunella vulgaris* L., *Leucanthemum vulgare* Lam. *Ranunculus repens* L., *Taraxacum officinale* (L.) Webb ex F.H.Wigg.	periodic haymaking	*D. hebridensis* (Wilmott) Aver	50 units
The western side of slope of the drainage ditch with coordinates 61^{0}00’47,7282’’N and 68^{0}59’50,2049’’ E	A motley grass-grasses association of technogenically altered landscape. (*Calamagrostis epigeios* (L.) Roth, *Equisetum arvense* L. , *Achillea millefolium* L., *Chamaenerion angustifolium* (L.) Scop., *Hieracium umbellatum* L., *Trifolium pratense* L., *Trifolium repens* L., *Calamagrostis langsdorffii* (Link) Trin. , *Agrostis gigantea* Roth *Poa angustifolia* L. *Elytrigia repens* (L.) Nevski, *Poa palustris* L., *Bromopsis inermis* (Leyss.) Holub, *Phleum pratense* L., *Poa pratensis* L., *Crepis tectorum* L., *Artemisia vulgaris* L. *Cirsium arvense* (L.) Scop, *Tussilago farfara* L., *Taraxacum officinale* (L.) Webb ex F.H.Wigg., *Potentilla anserina* L.	periodic haymaking	*D. hebridensis* (Wilmott) Aver *D. incarnata (L.) Soo.*	38 units 12 units

The identified technogenically altered ecotopes have a different parent rock (technogenic soils made of crushed stone and sand), a steep slope of the western exposure, special microclimatic conditions (additional slope moisture, protection from winds). Observation of plant growth in the spring-summer period did not reveal a negative effect of haymaking on the vegetation and flowering of representatives of the *Orchidaceae* family.

Careful status monitoring of the small population *C. trifida* is necessary since this plant probably does not grow every year and therefore finding it causes difficulties.

Thus, the protection measures for orchids are recommended. Their implementation involves the identification of characteristic habitats, monitoring the populations status in nature, protecting biotopes in places where orchids grow, reducing environmental loads, as well as *in vitro* orchids cultivation and their introduction.

An elaborate study of representatives of the *Orchidaceae* family will be surveyed in the future. The studied area will be located both on the "Samarovsky Chugas" territory and in adjacent territories. The discovering territories with orchids which are located outside the boundaries of the natural park allows us to make a proposal to expand the boundaries of protected areas.

REFERENCES

1. Антипов А.М. 2001. Результаты авиаучетов водоплавающих и околоводных птиц, рекомендованных в Красную книгу Ханты-Мансийского автономного округа // Актуальные проблемы изучения и охраны птиц Восточной Европы и Северной Азии. — Казань.
2. Атлас Ханты-Мансийского автономного округа — Югры. 2004. Том II. Природа и экология. Ханты-Мансийск — Москва. С. 125.
3. Байкалова А.С., Звягина Е.А. Dactylorhiza russowii (Klinge) Holub (Пальчатокоренник Руссова) Электронный гербарий Юганского заповедника. [Электронный ресурс] URL: http://ugansky.ru/activities/scientific/encyclopedya/166/1345/ (Дата обращения: 30.01.2020)
4. Большаник П.В. 2017. Геоэкологические проблемы трансформации рельефа урбанизированных территорий (на примере городов Западной Сибири) Большаник П.В., Недбай В.Н. М.: ИНФРА-М. С. 243.
5. Большаник П.В. 2010. Развитие ландшафтов Прииртышья и их антропогенная трансформация (на примере Среднего и Нижнего Прииртышья и Нижнего-Среднего Приобья) (монография) Lambert Academic Publishing. С. 207.
6. Вахрамеева М. Г., Денисова Л. В., Никитина С. В. 1991. Орхидеи нашей страны. М.: Наука. С. 222.
7. Волков И. А., Волкова В. С., Гуртовая Е. Е. 1973. О строении и условиях формирования отложений района г. Самарово // Плейстоцен Сибири и смежных областей. М.: Наука. С. 34-39.
8. Егорова Н.Ю., Егошина Т.Л. 2018. Новые местонахождения редких и нуждающихся в охране сосудистых растений выработанных торфяных месторождений (Кировская область) // Самарский научный вестник. Т. 7. №3. С. 35-41.
9. Крапивнер Р. Б. 1979. Самаровский феномен в Западной Сибири // Ледники или тектоника? Бюл. МОИП. Отд. геол. Т. 54, вып. 4. С. 79-93.
10. Красная книга Российской Федерации (растения и грибы). 2008. Москва.
11. Красная книга Ханты-Мансийского автономного округа — Югры : животные, растения, грибы. 2013. Екатеринбург: Издательство Баско. С.460.
12. Кусковский В.С. 2002. Особенности мониторинга геологической среды городского природного парка на севере Западной Сибири // Экология северных территорий России. Проблемы, прогноз ситуаций, пути развития, решения. Мат-лы межд. конф. Том 1. Архангельск. С. 641-645.
13. Летопись природы: отчет по НИР. 2017. БУ ХМАО-Югры «Природный парк «Самаровский чугас»; рук. Рыбьякова Н. Н.; исполн.: Меликов Д. Д. [и др.]. Ханты-Мансийск. С. 259. URL: http://samchugas86.ru/wp-content/uploads/2019/02/Летопись-природы-2017-ИТОГОВЫЙ-СО-СПИСКОМ.pdf (дата обращения 20.03.2019).
14. Мишагина Д.А. 2018. Виды семейства ORCHIDACEAE техногенно-измененных экосистем Ивановской области. Успехи современного естествознания. № 6. С. 102-106.
15. Обзор «О состоянии окружающей природной среды Ханты-Мансийского автономного округа в 2019 году». 2020. Гос. комитет по охране окружающей среды Ханты-Мансийского АО. Ханты-Мансийск.
16. Определитель растений Ханты-Мансийского автономного округа. 2006. Новосибирск — Екатеринбург: «Изд-во «Баско». С. 304.
17. Отчет Ханты-Мансийской геолого-съемочной партии о результатах групповой геологической съемки. 1985. М-б 1:200 000 листов -42-III-XII; XIV-IIX, 75-76, XXI-XXV, XXII в трех томах. Т 1. Книга 2.
18. Постановление Правительства Ханты-Мансийского автономного округа — Югры от 12 июля 2013 года № 245-п «О концепции развития и функционирования системы особо охраняемых природных территорий Ханты-Мансийского автономного округа — Югры на период до 2030 года (с изменениями на 26 апреля 2019 года) http://www.docs.cntd.ru (дата обращения 23 августа 2019 года).
19. Распоряжение Правительства Российской Федерации от 31 августа 2002 года N 1225-р «Об одобрении Экологической доктрины Российской Федерации» http://docs.cntd.ru/document/901826347 (дата обращения 23 августа 2019 года).
20. Ценопопуляции растений (очерки популяционной биологии). 1988. М.: Наука. 184 с.
21. Черепанов С.К. 1995. Сосудистые растения России и сопредельных государств (в пределах бывшего СССР). СПб.: Мир и семья. С. 992.
22. Чиркова Н.Ю., Егошина Т.Л. 2011. Проявление черт эксплерентности некоторых видов семейства Orchidaceae Juss. в антропогенно измененных экосистемах // Охрана

и культивирование орхидей: материалы IX междунар. конф. (26-30 сентября 2011). М.: Товарищество научных изданий КМК. С. 466-468.

23. Шепелева Л.Ф., Лукьяненко Д.Н. 2009. Состояние популяций орхидных на территории междуречья Большого Салыма и Иртыша // Вестн. Том. гос. ун-та. №326.

Received: 13.03.2021
Revised: 15.05.2021
Accepted: 25.06.2021

УДК 504.05: 581.192
DOI: https://doi.org/10.17816/edgcc41876

BIOGEOCHEMICAL ASSESSMENT OF THE MAIN PLANTS AT THE NADYM DISTRICT'S REINDEER PASTURES (YAMAL-NENETS AUTONOMOUS OKRUG)

E.V. Agbalyan[1], E.A. Zarov[2], I.V. Filippov[2], Yu.A. Pechkina[1], E.V. Shinkaruk[1], K.V. Yulbarisova[1], N.A. Khnycheva[1], E.D. Lapshina[2]

[1] State Public Institution of Yamalo-Nenets Autonomous Okrug «Scientific Research Centre of the Arctic»;
[2] Federal State Budgetary Institution of Higher Education "Yugorsk State University"

Corresponding author: E.V. Agbalya, e-mail: agbelena@yandex.ru

Citation: Agbalyan E.V., Zarov E.A., Filippov I.V., Pechkina Yu.A., Shinkaruk E.V., Yulbarisova K.V., Khnycheva N.A., Lapshina E.D. 2021. Biogeochemical assessment of the main plants at the Nadym district's reindeer pastures (Yamal-Nenets autonomous okrug) // Environmental dynamics and global climate change. V. 12. N 1. P. 27–41. DOI: https://doi.org/10.17816/edgcc41876

The chemical elemental composition of the most widespread species of wood (Betula pubescens, Larix sibirica, Pinus sylvestris, Salix lanata), shrubs (Vaccinium vitis-idaea, Ledum palustust sl), herbs (Eriophorum angustifolium, Equisetum arvense) and lichens (Cladonia stellaris, Cladonia stygia). The concentrations of Cr, Co, Ni, Cu, Zn, Ga, As, Y, V, Na, Mg, Si, P, S, K, Ca, Ti, Mn, Fe, S obtained using the method of retgenofluorescence energy dispersion analysis.

The features of the local biogeochemical background of plants are revealed and their geochemical specialization is studied. The greatest difference in the level of accumulation between different plant species was found for Ni, Zn, Ca, Mn, S, and Si. The analysis of the accumulation coefficients of chemical elements in plants relative to the local background level is carried out. Statistical significant differences in the elements accumulation by plants in different bioclimatic zones were revealed for Cu, Fe, Co, Cr, As, Mg, V, Y.

The studied plants according to environmental safety criteria and the content of normalized micro- and macrocells mainly meet the requirements for fodder plants. The exception is the low content of nutrients Co, Na and K. For the prevention of animal diseases associated with a deficiency of essential elements, it is necessary to optimize the diet of deer by enriching feed with biologically active substances and macro- and microelements.

Keywords: plants; chemical elements; species specificity; biogenic elements; deer pastures; environmental safety; Nadym district; Yamalo-Nenets Autonomous Okrug; Western Siberia

INTRODUCTION

Plants are the most important component of the biosphere and a link in the food chain in biogeochemical migration of macro-and microelements from rocks and soils to living organisms. The natural heterogeneity of environmental chemical composition and intensive anthropogenic activities lead to an imbalance of biologically active substances in plants, feed and the animal body [Bityutsky, 2011; Pozov, Orlova, 2012].

The forage plants are considered one of the sources of toxic substances entering the animal body. Under conditions of anthropogenic pollution, more intensive involvement of heavy metals in the biological cycle is recorded [Opekunova, 2019]. Large amounts of chemical elements which have toxic effect can accumulate in the body of animals and induce a specific disease – microelementosis [Avtsyn, 1972].

Of scientific and applicative interest are studies devoted to the following three fields: 1) biogeochemical features of the elemental composition of plants growing in background areas within the boundaries of the oil and gas industry location; 2) identification of the specific features of chemical elements accumulation in plants; 3) the geographical features of the chemical elements accumulation by plants.

The purpose of this paper is to identify the features of elemental composition and estimate the quality of some plant species that compose the reindeer food base in different bioclimatic zones of the Nadymsky region.

MATERIALS AND METHODS

We sampled 8 plant species and 2 species of feeding lichens[1] in July-August 2019 in the background areas of the Nadymski Region of the Yamalo-Nenets Autonomous Okrug (YNAO) during the geobotanical exploration. These samples were taken for determining their elemental composition. Within the Nadymski Region several natural subzones are distinguished: south tundra, forest tundra, north taiga [YNAO Atlas, 2004]. Plant samples were taken at three sites (Fig. 1). Field №1 is located

[1] For simplification, lichens are hereinafter referred to as vegetation.

DOI: https://doi.org/10.17816/edgcc41876

in the north taiga subzone, in the open larch and firry-larch suffruticous-lichen forests, in the area of the village “Priozerny”. Filed №2 is located in the forest tundra subzone, in the larch-birch with small areas covered by fir suffruticous-green moss-lichen open forests and open woods, in the area of the city Nadym. Filed №3 is located in the south tundra subzone, in the suffruticous-green moss with willow, dwarf birch and with area covered by alder stand grumous and maculiferous-grumous tundra, in the area of the village Yamburg. A total of 90 samples were taken.

The phytomass ultimate composition of the following species is determined: leaves of *Betula pubescens* Ehrh., *Salix lanata* L., bark of *Larix sibirica* Ledeb., needle of *Pinus sylvestris* L., vegetative green aboveground parts of *Vaccinium vitis-idaea* L., *Ledum palustre* L. (incl. *L. Decumbens* (Aiton) Lodd. ExSteud.), *Eriophorum angustifolium* Honck., *Equisetum arvense* L., thallome of lichens *Cladonia stellaris* (Opiz.) Pouzaret Uezda и *Cladonia stygia* (Fr.) Ruoss.

The above-mentioned species were sampled in three replications for each bioclimatic subzone. A characteristic ecosystem was selected at each 10×10 m sampling site and samples were taken from at least 10 individual plants for each species. Due to the area heterogeneity and the difference in environmental drivers, 10-18 sampling sites were organized for the ability of taking the entire list of plant species in each subzone (Fig. 1, Table 7 in Appendix). The mass of each sample was at least 0.2 kg. In the laboratory, the samples were dried to constant weight in a drying cable ($t = 80°C$) and

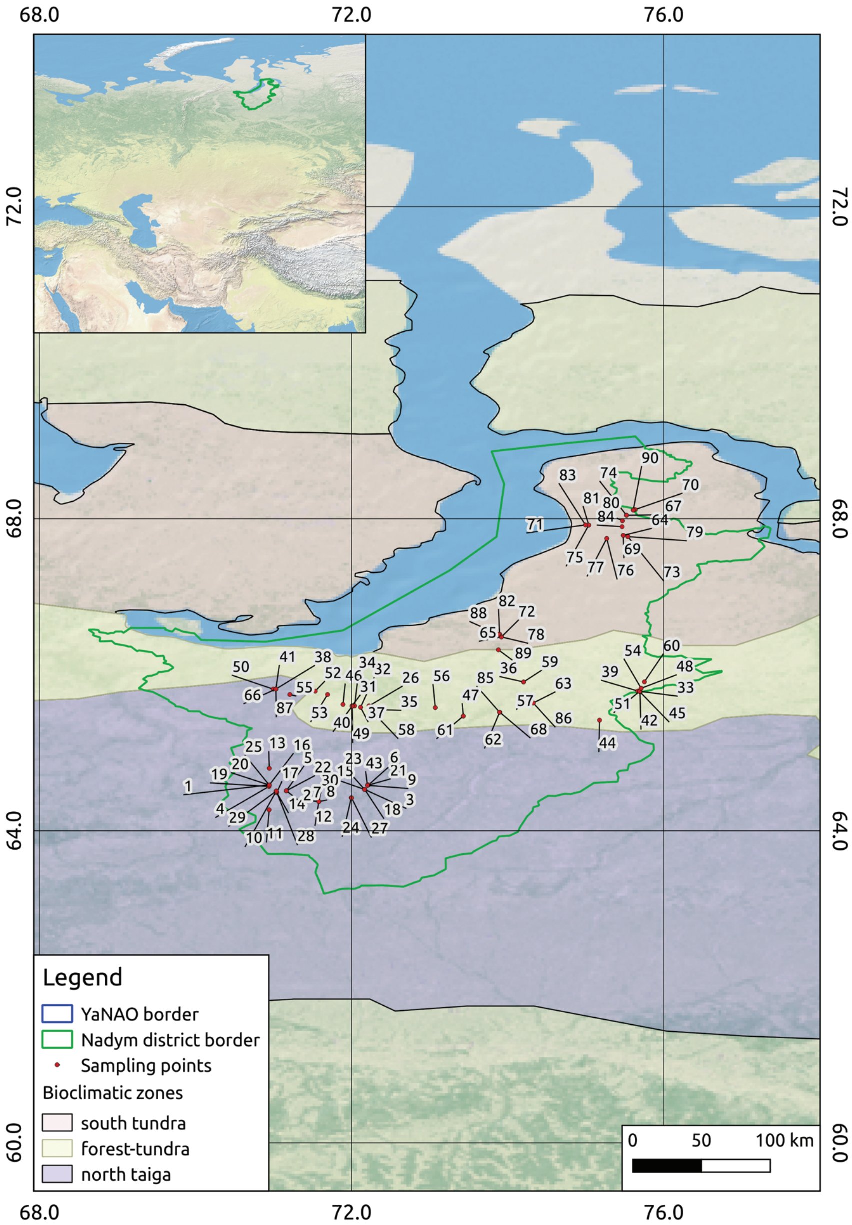


Fig. 1. Sampling sites at the Nadymski region area, YNAO

grinded in a mechanical mill to a powdery state.

In this work, we took advantage of the method of X-ray fluorescence energy-dispersion analysis (FED) using the BRA 135-f spectrometer (Joint-Stock Company Scientific and Production Enterprise "Burevestnik", Saint Petersburg). The content of the elements Cr, Co, Ni, Cu, Zn, Ga, As, Y, V, Na, Mg, Si, P, S, K, Ca, Ti, Mn, Fe, Sr was determined in the phytomass samples. The elements concentrations were calculated for the air-dry weight.

The analytical $K\alpha$ – line was studied. The selection of analytical lines for measuring the radiation intensity of the elements was accomplished in the appropriate wavelength range. The total radiation intensity was determined as a sum of the secondary characteristic and primary diffuse radiation. Operating mode: for the medium area –19 kV, 100 Ma; for the heavy area – 50 kV, 60 Ma. A primary radiation filter is made of zirconium.

State standard reference samples (SSRS) were used to plot the calibration characteristics: LB-1 (composition of birch leaf); EC-1 (composition of *Elodea canadensis*); GM-1 (composition of grass mixture). Standard reference plant samples were used to assess the results validation. Calibration and standard samples were prepared for the X-ray FED in the same way as the studied plant samples. The values of the detection limits were established applying standard reference samples with low element content: Cr – 0.4 mcg/kg, Co – 0.02 mg/kg, Ni – 0.3 mg/kg, Cu – 0.4 mg/kg, Zn – 1.1 mg/kg, Ga – 0.02 mg/kg, As – 0.02 mg/kg, Y – 0.02 mg/kg, V – 0.09 mg/kg, Na – 30 g/kg, Mg – 200 mg/kg, Si – 400 mg/kg, P – 60 mg/kg, S – 200 mg/kg, K – 300 mg/kg, Ca – 300 mg/kg, Ti – 12 mg/kg, Mn – 30 mg/kg, Fe – 50 mg/kg, Sr – 7 mg/kg. The error extent (results reproducibility) for the studied elements varied from 5% to 10%.

Previous studies have shown that soils of the studied region are characterized by a significant deficiency of elements [Opekunova et al., 2007; Ieronova et al., 2014; Tomashunas et al., 2014; Agbalyan et al., 2015; Zhurba et al., 2016; Strahovenko et al., 2016; Skipin et al., 2016; Agbalyan et al., 2018; Alekseev et al., 2019; Semenkov, 2019]. These researches were pursued in the territory unaffected by anthropogenic activity. To estimate the elements backgrounds the median values shown in results of all the above-mentioned studies for mineral soils of the Nadym region were used.

To identify the zonality of chemical elements accumulation by plants, species found in all bioclimatic subzones were chosen. These species may be used as bioindication objects as well. Out of general list of studied species, *Betula pubescens* and *Pinus sylvestris* were not found in the tundra zone and due to this fact were excluded from the analysis.

The sample under study is different from the normal distribution. As a consequence, the statistical processing of analytical data included the determination Med (median), the 1st and 3rd quartiles. For comparative estimates, the Kruskal-Wallis test was applied, as well as a nonparametric method of set membership test of two and more samples followed by the application of the Dunn test for pairwise comparison. The sample size was 90 measurements for correlation analysis (Fig. 3), 9 measurements for estimating the specific geochemical specialization of plants (Fig. 4) and 30 measurements to assess the content of elements in plants of various bioclimatic subzones (Fig. 5). Data processing, analysis and plotting were performed in the R software product applying the rstatix, ggplot2 and ggpubr packages.

RESULTS AND DISCUSSION

Bioclimatic plants features

The major drivers which characterize the content of chemical elements in plants are climatic, landscape-geochemical features and species specificity of elements accumulation by plants. The content

Table 1

Biological absorption factors of the chemical elements in plants with regard to the background in soils at this region[1]

Major elements	$P_{22.4}$, $Mg_{9.1}$, $Mn_{8.0}$, $Ca_{6.2}$, $Zn_{1.5}$
Scarce elements	$Cu_{0.9}$, $Y_{0.4}$, $As_{0.2}$, $Ni_{0.2}$, $Cr_{0.1}$, $Ti_{0.09}$, $K_{0.08}$, $Sr_{0.07}$, $Na_{0.03}$, $Si_{0.02}$, $V_{0.0007}$, $Co_{0.005}$, $Fe_{0.005}$

Table 2

The coefficients of biological absorption of chemical elements in plants (K_{62}) with regard to clarke concentrations in the top layer of terrestrial Earth crust

Major elements	$P_{4.3}$
Scarce elements	$Mn_{0.98}$, $Zn_{0.5}$, $Mg_{0.4}$, $Cu_{0.2}$, $Y_{0.1}$, $As_{0.08}$, $Ca_{0.08}$, $Ni_{0.07}$, $Cr_{0.06}$, $Ti_{0.04}$, $Si_{0.03}$, $Sr_{0.03}$, $K_{0.01}$, $V_{0.002}$, $Na_{0.001}$, $Fe_{0.001}$, $Co_{0.001}$

[1] Data of Ga and S background concentrations in the soils of the YNAR were not found

of chemical elements depends on the spatial heterogeneity of each species habitat. Climate is one of the most important factors that determines the biogeochemical specialization of the flora and the correlation between all migration types of chemical elements in the landscape. In a humid climate, mainly catiophile plants are formed with a predominant high accumulation of cationic elements [Skarlygina-Ufimtseva, 1991]. In landscapes with an acidic class of water migration, cationic elements that are easily absorbed by vegetation migrate actively.

The analysis of the median content of macro- and microelements in the samples of all studied plants showed some features and differences in the elements accumulation both amongst plant species and bioclimatic subzones (Fig. 2, Table 4-6). It was established that the soils of the studied site are characterized by a significant deficiency of elements.

According to a value of the median content in plants, the elements are arranged in the following descending order (mg/kg): Si(8827) > Mg(6469) > Ca(3186) > P(2955) > Mn(752) > S(210) > Ti(137) > Zn(33.9) > Cu(8.3) > Sr(7.0) > Cr(5.3) > Ni(3.4) > Y(2.6) > As(0.47) > V(0.2) > Ga(0.09)[1].

The phytogeochemical spectrum is a ranked series of chemical elements in descending order of the biological absorption factor K_{61} (the ratio of the chemical elements content in plants to the background content in the soils of the Yamal-Nenets Autonomous Region [Opekunova et al., 2007; Ieronova et al., 2014; Tomashunas et al., 2014; Agbalyan et al., 2015; Zhurba et al., 2016; Strahovenko et al., 2016; Skipin et al., 2016; Agbalyan et al., 2018; Alekseev et al., 2019; Semenkov, 2019]. The spectrum allows us to identify the intensity of elements accumulation in the studied plant samples (Table 1).

Phosphorus is a biogenic element and accumulates in plants of the Nadym region in the maxi-

[1] Median values of Na, Fe, K, Co and Sr concentrations are under the limit and that is the reason they are delisted.

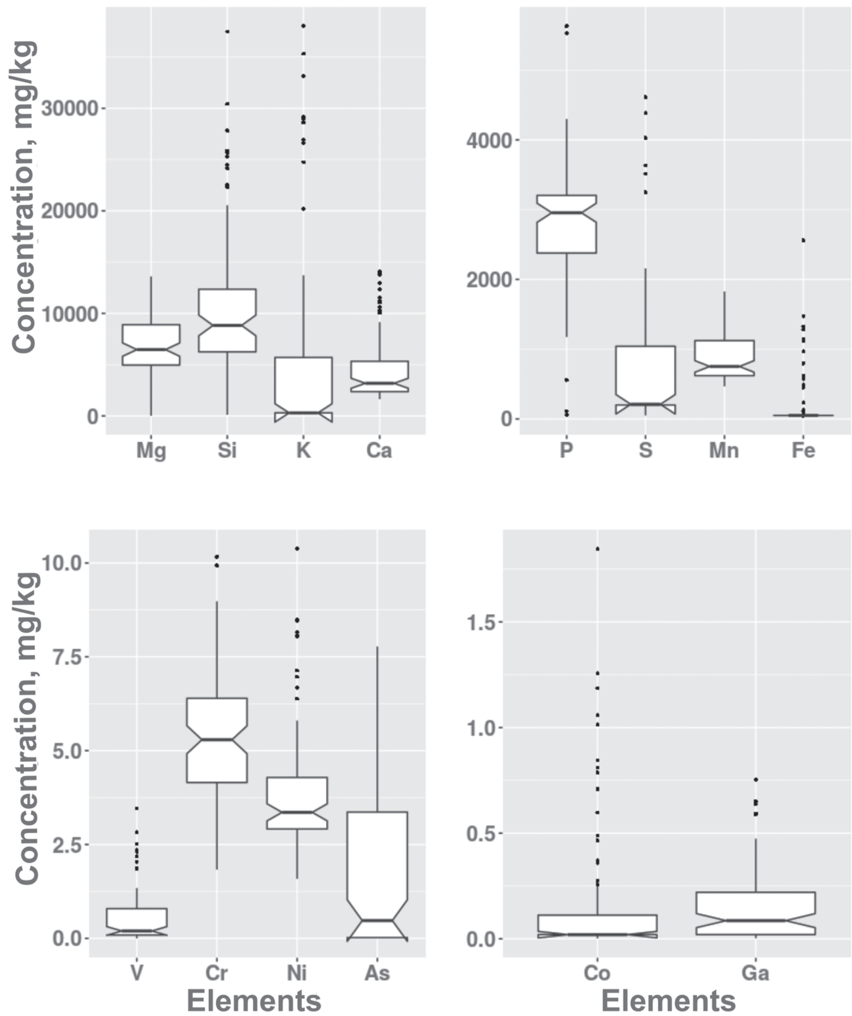


Fig. 2. Values of obtained elements concentrations. The line indicates the median, the lower and upper boundaries of block are the lower and upper quartiles, the notches show a confidence interval relative to the median, the error bars are 1.5 interquartile values (~3σ), the points are outliers (everything beyond the error bars)

DOI: https://doi.org/10.17816/edgcc41876

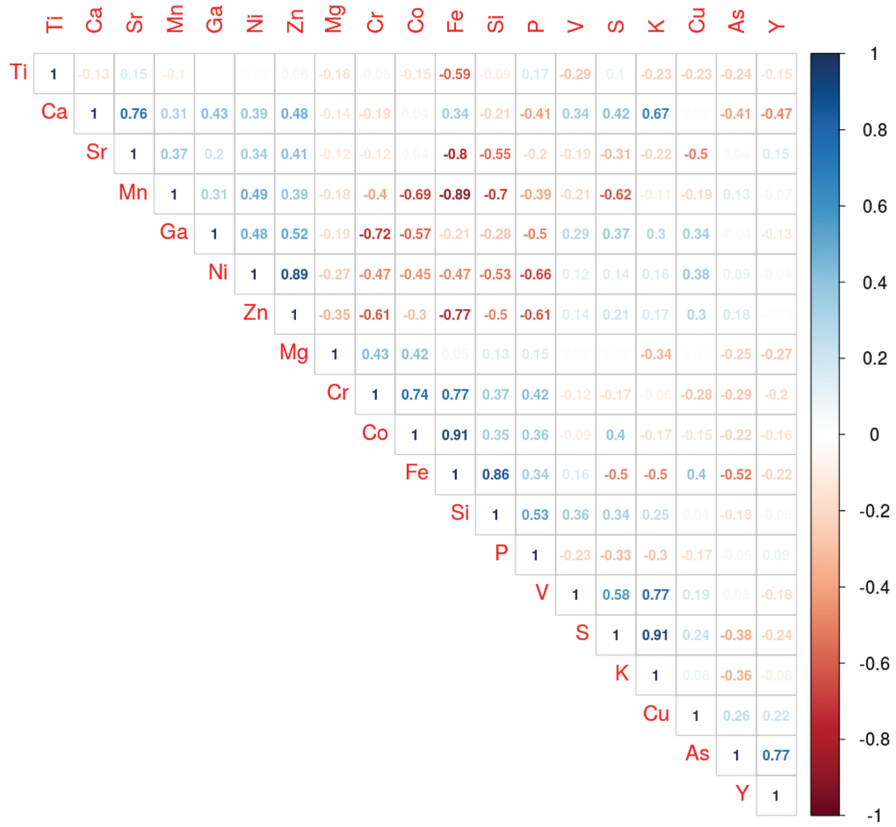


Fig. 3. *Correlation matrix among the elements concentrations in plants (according to the Spearman's test)*[1]

mum amount. Although its concentration in soils is fairly low (132 mg/kg), its content in plants is ~22 times higher.

Magnesium, manganese and calcium are characterized by a high coefficient of biological absorption, despite their competitive ions in accumulation. Magnesium is involved in the processes of photosynthesis, phosphorus transport and other vital functions [Marschner, 2011; Voevodina, 2015]. Manganese is an indicator of biogeochemical cycles in landscapes with a humid climate. The accumulation of Mn in plants is associated with a change in the mobility of chemical elements simultaneously with sandy soils are replaced by peat bogs [Opekunova, 2013]. Calcium is involved in the construction of cell walls and membranes [White, 2003]. Plants accumulate zinc one and a half times more than its background content in soils. This element is involved in large amount of biochemical processes.

For the convenience of comparing the results with the eminent works of V.V. Dobrovolsky and A.I. Perelman, the biological absorption factors (Kb2) of chemical elements with respect to clarke conentrations were calculated [Grigoriev, 2009]. The results (Table 2) found the accumulation of only phosphorus in plants of the Nadym region, the remaining elements are contained in vegetation in much lower concentrations.

The estimation of the chemical elements associations is of our interest and based on the correlation dependencies among their content in the studied plant samples. This approach allows us to establish the role of anthropogenic load and physiological features of absorption, the specifics of pollution sources. The accumulation of chemical elements in plants exposed to the simultaneous influence of various factors is tied to pollutants effluence in different ways. Antagonistic elements and synergistic elements have been identified in specific geochemical conditions within the Nadymsky region.

Statistically significant associations of elements were established for all plants (Fig. 3). A positive significant correlation within the groups V – S – K (r_s = 0.58-0.91) and Mg – Cr – Co – Fe – Si – P (r_s = 0.15–0.91) as well as a strong relationship of As – Y (r_s = 0.77), Ni and Zn with each other (r_s = 0.89) and with Ca, Sr, Ga, Mn r_s = 0.2–0.76).

It is known that the lack or excess of some elements can block the absorption or metabolism of other chemical elements [Ermakov et al., 2018].

[1] Na is excluded from the analysis due to the concentration values are less than detection limits for all studied samples.

In this study, elements with a significant inverse correlation were identified, i.e. a high content of one element is usually associated with a low content of another. Such antagonist elements include the associations Si with Zn ($r_s = -0.77$), Sr ($r_s = -0.8$) and Mn ($r_s = -0.89$), as well as among the groups Mg, Cr, Co, Fe, P and Sr, Mn, Ga, Cu, Ni, Zn ($r_s = -0.12 - -0.72$).

The most important and normalized macronutrients in animal's food ration are Ca, K, Mg, P, Na, S, microelements – Fe, Mn, Zn, Cu, Co. In the studied plant samples, the median contents of Mg, P and Mn exceed the recommended values (normal range) in cattle feed [Biogeochemical bases..., 1993]; the median contents of Zn, Cu, Fe and Si in plants meet normal range, and the concentrations of Co, Na, K are in short supply.

The existing problems of the reindeer husbandry development in the Yamalo-Nenets Autonomous Okrug are associated with the food potential depletion at the deer pastures in the tundra biome [Zuev, 2016]. These problems can be partially solved by more active involvement of natural forage lands of the Nadymsky region in the stream of commerce. The forage base of the Nadymsky region is represented by fruticose lichens, shrubby

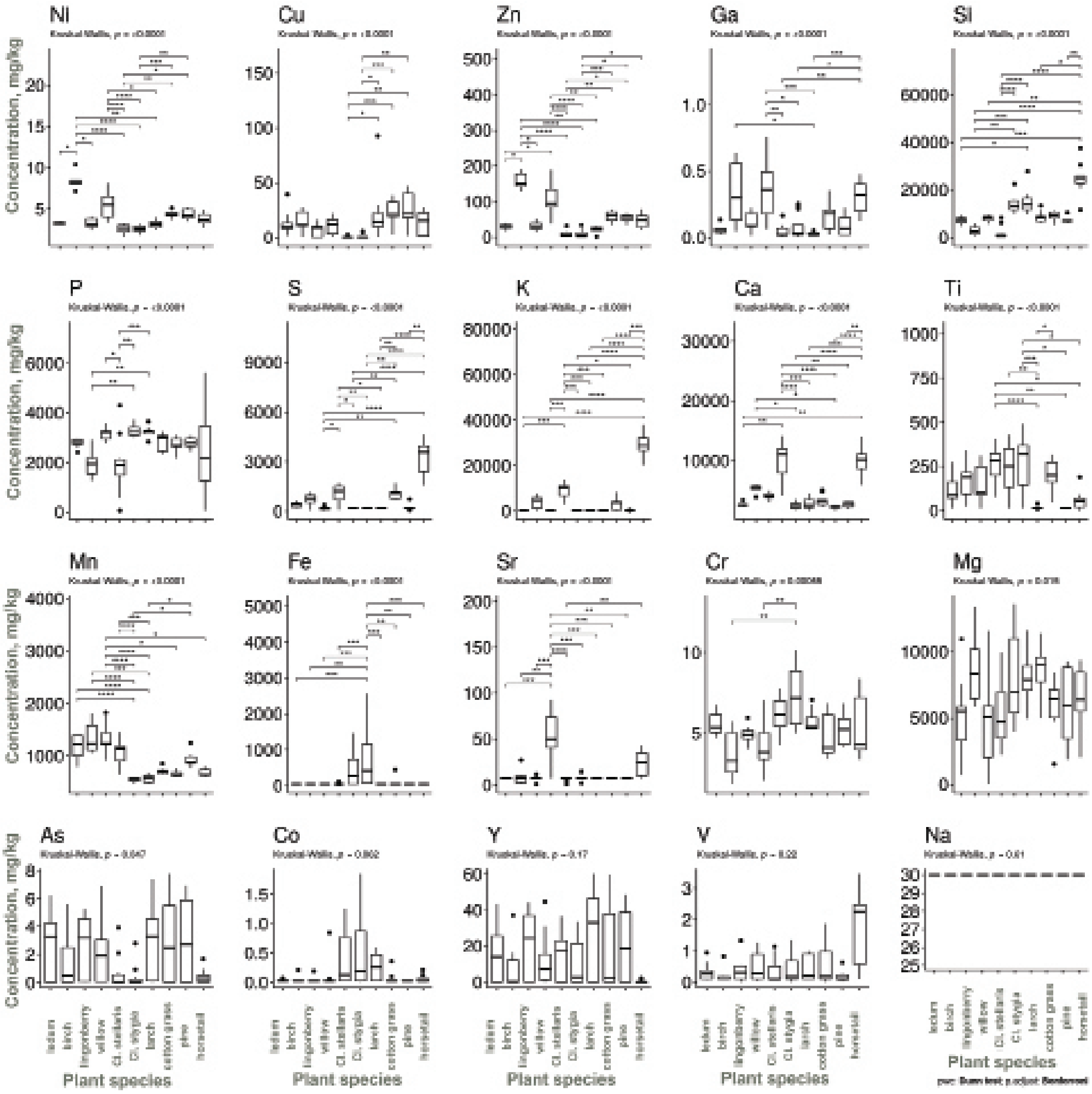


Fig. 4. Accumulation of elements by various plant species. Plant species with statistically significantly different concentrations are marked with brackets, the significance of differences is marked with asterisks (*– a weak significant difference, ***** – a strong difference)

DOI: https://doi.org/10.17816/edgcc41876

willows and birches, sedges, cereals, plants of the group of miscellaneous herbs including composite flowers and equisetic family [Baykalova and Dolgova, 2018]. At the same time, the norm of deer herds should be strictly taken into account in order to prevent vegetation degradation.

The specific geochemical specialization of plants

The biogeochemical specialization of plants depends on the zonal-regional patterns of biogenous element migration, specific organization level of phytobiota and the degree of anthropogenic load [Shikhova, 2017]. The specificity of the element accumulation by plants in wild landscapes is manifested at the ecobiomorphic level of the phytobiota organization. There are two main groups of plants determined by evolutionarily developed adaptation strategies: concentrators and deconcentrators [Ufimtseva, 2015]. Concentrators accumulate chemical elements, both at low and at high content in the soil, soil-forming and bedrock. Deconcentrators are plants in which the supply of chemical elements to the aboveground part is limited, despite their high content in their surrounding area.

The specific geochemical specialization of plants was studied (Fig. 4, Table 5). The content of Mg and minor plant nutrients (V, Y, As and Co) does not differ statistically significantly amongst the studied plant species. For the remaining elements, differences were revealed for several pairs of plants. The greatest difference in the level of accumulation among the different plant species was found for Ni, Zn, Ca, Mn, S and Si.

Vanadium content varies from 0.09 mg/kg in the needles of *Pinus sylvestris* and thallomes of *Cladonia stellaris* to 2.25 mg/kg in *Equisetum*

Table 3

The biological absorption factors (K_{61}) of chemical elements in plants according to calculated local baseline concentrations in soils of the YNAO (elevated accumulation levels are indicated in bold, reduced accumulation levels are indicated in italics)

The chemical element	*Cladonia stellaris*	*Cladonia stygia*	*Eriophorum angustifolium*	*Equisétum arvénse*	*Lédum palustre*	*Vaccínium vítis-idaéa*	*Salix lanata*	*Betula pubescens*	*Larix sibirica*	*Pínus sylvéstris*	Localbackground,mg/kg^{1}
V	0.46	0.92	0.96	11.51	1.36	1.59	1.42	0.53	1.04	0.46	0.20
Cr	1.21	1.42	0.81	0.85	1.06	0.97	0.75	0.64	1.06	1.03	5.29
Co	5.50	9.80	-	-	-	-	-	-	12.75	-	<0.02
Ni	0.80	0.75	1.28	1.01	0.99	0.95	1.64	2.47	0.93	1.25	3.36
Cu	*0.05*	*0.05*	2.37	1.73	1.14	0.98	1.33	1.26	1.63	2.44	8.82
Zn	*0.10*	*0.09*	1.51	1.20	0.77	0.80	2.41	3.84	0.56	1.47	33.86
Ga	0.26	0.38	2.31	4.14	0.68	1.14	4.65	3.90	*0.26*	0.86	0.09
As	*0.04*	*0.04*	5.26	0.46	6.95	6.73	4.02	1.01	6.97	5.73	0.47
Y	6.52	1.08	1.00	*0.01*	5.38	9.27	2.72	*0.07*	12.65	7.17	2.63
Na	-	-	-	-	-	-	-	-	-	-	<30.0
Mg	1.08	1.22	1.01	0.99	0.85	0.80	0.73	1.29	1.40	0.92	6469.0
Si	1.36	1.69	1.13	3.06	0.87	1.00	*0.05*	*0.30*	1.00	0.86	8827.0
P	1.16	1.17	0.96	0.77	1.00	1.15	0.68	0.70	1.08	1.00	2955.0
S	0.95	0.95	5.22	17.01	1.94	0.95	5.79	3.80	0.95	1.01	210.0
K	-	-	12.58	95.98	-	-	34.58	15.38	-	-	<300.0
Ca	0.79	0.89	0.81	3.57	0.90	1.38	3.90	1.88	1.07	0.93	3186.0
Ti	1.74	2.22	1.38	0.36	0.60	0.69	1.96	1.31	*0.08*	*0.1*	137.0
Mn	0.70	0.74	0.81	0.81	1.55	1.56	1.44	1.67	0.89	1.11	752.0
Fe	5.40	8.50	-	-	-	-	-	-	-	-	<50.0
Sr	-	-	-	3.50	-	-	7.14	-	-	-	<7.0

arvense (Table 5). The increase of V concentration is established in the following row: *Betula pubescens* > *Cladonia stygia* > *Eriophorum angustifolium* >*Larix sibirica*>*Ledum palustre (incl. decumbens)*>*Salix*>*Vaccinium vitis-idaea*.

The high content of Cr is found in all sampled plants. The concentration of Cr varies insignificantly from 3.3 mg/kg in the leaves of *Betula pubescens* to 7.2 mg/kg in the thallomes of *Cladonia stygia*.

The Co content is below the detection limit in a major part of the studied samples. Heterogeneity and elevated concentrations were found in lichen thalloms and larch bark, which indicates local features of the cobalt distribution.

A pronounced accumulation of Ni was found in the leaves of *Betula pubescens* — 8.3 mg/kg. The lowest values were found for *Cladonia stellaris* and *Cladonia stygia*.

In the tested sample of plants, the Cu content varies from 0.4 (decision limit) to 21.6 mg/kg. Thus, in the thallomas of *Cladonia stellaris* and *Cladonia stygia*, the Cu content varies from 0.4 mg/kg to 5.5 mg/kg (the median value is 0.4 mg/kg), in the needles of *Pinus sylvestris*, the Cu content varies from 1.6 mg/kg to 47.4 mg/kg (the median value is 21.6 mg/kg).

The maximum accumulation of zinc is found in leaves of *Betula pubescens* and leaves of shrubs of

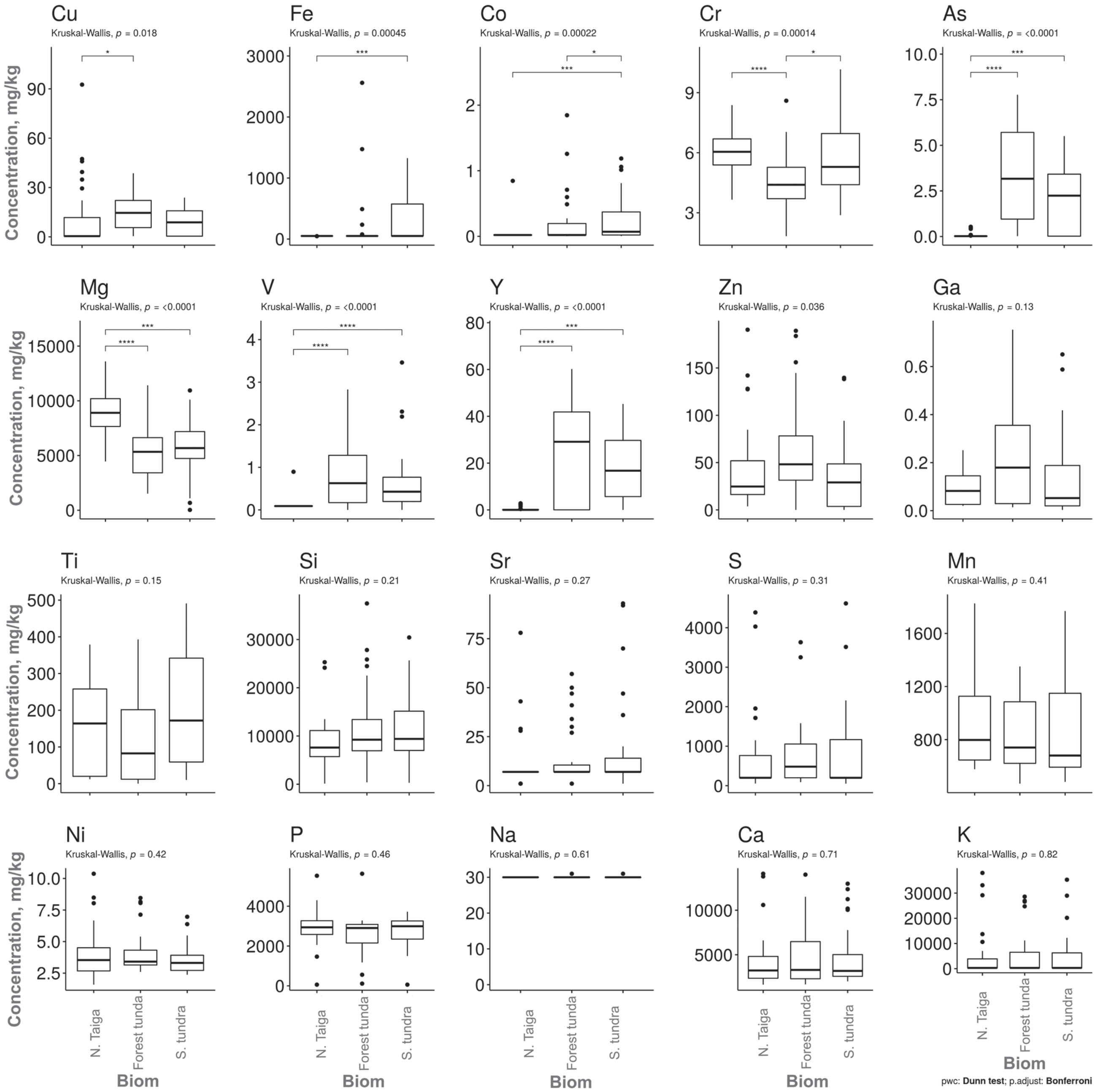


Fig. 5. The content of elements in plants at different bioclimatic subzones of the Nadymsky region, YNAO. Plant species with statistically significantly different concentrations are marked with brackets, the significance of differences is marked with asterisks (* — a weak significant difference, ***** — a strong difference)

DOI: https://doi.org/10.17816/edgcc41876

the genus *Salix*. The Zn concentrations in *Betula pubescens* leaves varies from minimum values of 128 mg/kg to maximum values of 190 mg/kg (median value is 150 mg/kg). In the shrubs leaves (of the genus *Salix*), Zn accumulations vary from 38 mg/kg to 140 mg/kg (the median value is 94 mg/kg). The minimum Zn content was established in *Cladonia stellaris* and *Cladonia stygia* (3.7–3.9 mg/kg).

The leaves of shrubs of the genus *Salix* actively accumulate Ga in concentrations from 0.06 mg/kg to 0.75 mg/kg (the median content is 0.36 mg/kg). Minimum Ga levels were established in *Larix sibirica* and *Cladonia stellaris* (0.02 mg/kg).

The maximum As content is found in *Larix sibirica* at 3.31 mg/kg (from 0.02 mg/kg to 7.40 mg/kg) and in *Ledum palustre* at 3.29 mg/kg (from 0.02 mg/kg to 6.23 mg/kg). The lowest concentrations of As are shown in samples of fruticose lichens (0.02 mg/kg).

In the studied plants, the Y content varies widely from 0.02 mg/kg (detection limit) in the grass *Equisetum arvense* to 33.3 mg/kg in the bark of *Larix sibirica*.

A low Na content less than the detection limit (30 mg/kg) is shown in all studied plant samples. The analysis revealed two significant outliers of 420 and 920 mg/kg values for cranberries and willow leaves which we associate with accidental contamination of the selected samples.

The maximum amount of Mg accumulates in the leaves of *Betula pubescens* – 8300 mg/kg and in the bark of *Larix sibirica* (8990 mg/kg).

All the studied plants are enriched with silicon. In *Salix* leaves, Si concentrations are minimal and vary from 400 mg/kg to 8190 mg/kg. The maximum Si content was found in *Equisetum arvense* and *Cladonia stellaris, Cladonia stygia* (24,890 mg/kg, 13220 and 13730 mg/kg, respectively).

The maximum accumulation of P is characterisctic for *Vaccinium vitis-idaea, Cladonia stellaris* and *Cladonia stygia* and varies from 3210 mg/kg to 3250 mg/kg.

Equisetum arvense L. can accumulate maximum concentrations of S, K, Ca in comparison with other studied plants.

The Ti content in plants varies from 12 mg/kg in the bark of *Larix sibirica* to 320 mg/kg in *Cladonia stygia*. High Ti concentrations were found in *Cladonia stellaris* and in the leaves of *Salix lanata* – 251 and 282 mg/kg.

In the studied sample of plants, the Fe content is mainly at the level of the determination limit of 50 mg/kg, excaept thallomes of lichens *Cladonia stellaris* and *Cladonia stygia*, in which the Fe concentration varies from 50 mg/kg to 2560 mg/kg (median values of 270 and 25 mg/kg).

The maximum concentrations of Mn were recorded in the leaves of *Ledum palustre, Betula pubescens* and *Vaccinium vitis-idaea* (median values from 1230 mg/kg to 1240 mg/kg).

The Sr concentrations in the studied sample of plants are below the detection limit. The maximum concentrations were recorded in the leaves of shrubs of the genus *Salix* (from 7 mg/kg to 93 mg/kg) and in *Equisetum arvense* (from 7 mg/kg to 43 mg/kg).

The analysis of **the biological absorption factor of chemical elements in plants relative to the local baseline concentrations in soils of the Yamal-Nenets Autonomous Okrug** (Table 3) allowed us to identify a group of concentrator plants ($K_{бl}$>1.5), plant species with a background content of elements and a group of deconcentrating plants ($K_{бl}$<0.5). Strong concentration abilities were found only in *Equisetum* in terms of potassium content ($K_{бl}$ = 96).

Equisetum arvense, which is capable of accumulating 3–17 – fold amounts of V, S, Ga and Ca in comparison with other plant species, belongs to the accumulator plants of chemical elements. The lichens *Cladonia stygia* and *Cladonia stellaris* have the ability to concentrate Fe and Co, while *Cladonia stellaris* has specific features in the Y accumulation. *Eriophorum* accumulates K, S and As, *Ledum palustre* accumulates As and Y. *Salix lanata* accumulates high amounts of K, Sr, Ca and Ga; *Betula pubescens* leaves are Zn and Ni concentrators; *Larix sibirica* contains an increased content of Co and Y in the bark; *Pinus sylvestris* actively accumulates Cu.

Below the background values the content of elements in *Cladonia stellaris* and *Cladonia stygia* (Cu, Zn, As, Ga)*, Equisetum arvense* (Y, Ti), *Salix lanata*(Si), *Betula pubescens*(Y, Si), *Larix sibirica*(Ga, Ti), *Pinus sylvestris* (Ti) is represented.

Zonal features of chemical elements accumulation by plants

All the results obtained were combined to characterize the food supply of different biomes. Thus, on that ground, the territory can be characterized by the degree of favorability for grazing deer. Statistical significant differences in the element accumulation by plants in different bioclimatic subzones (Fig. 5, Table 6) were detected for Cu, Fe, Co, Cr, As, Mg, V, Y. No specific features in accumulation was detected for the remaining elements.

The data obtained found that the territory of the northern taiga is characterized by a low content of Fe, Co, As, V and Y and an elevated concentration of Mg and Cr in plants. Low concentrations of elements are due to the dominance of sandy meager bedrocks and podzols formed on them [Opekunova, 2013; Moskovchenko et al., 2015]. The territory of the forest tundra is characterized by an elevated content of As. The data obtained in this

DOI: https://doi.org/10.17816/edgcc41876

work are consistent with the results of soil studies [Alekseeva et al.]. The Yamal-Nenets Autonomous Okrug has an increased regional background for As [Alekseev et al., 2019]. According to the Cu content, a slight increase in the concentration from the North taiga subzone to the southern tundra was revealed.

For the forest-tundra subzone, elevated concentrations of Fe were found in cladonies, and for *Eriophorum angustifolium* the elevated Fe concentrations were found only in the southern tundra subzone. In the northern taiga subzone, increased concentrations of V accumulate in *Larix sibirica*. *Salix* accumulates maximum concentrations of Co in the northern taiga subzone. In contrast, the cladonies have minimum values in this subzone, which increase to the north. *Equisetum arvense* and *Salix* accumulate Cu in small quantities in the northern taiga subzone; on the contrary, an increased content of this element was found in *Larix sibirica*. The content of Ga is significantly higher in *Betula pubescens* leaves and in *Eriophorum angustifolium* in the forest-tundra subzone than the content of this element in *Salix* in the northern taiga subzone.

Differences in the accumulation of some elements in plants may be related to the peculiarities of their inflow from the atmosphere to the plant surfaces as part of individual fractions of silt-aerosol precipitation [Tentyukov, 2008]. An increased content of heavy metals (in particular, Zn, Cr and Ni) was found in the vegetation of the Western Taimyr which is a geochemical feature of the boreal zone, according to the authors [Syso et al., 2014].

It was shown in [Opekunova et al., 2018] that the increased content of heavy metals in vegetation is an indicator of the general pollution of the territory. At the same time, lichens are characterized by an elevated content of all elements. Birch is characterized by an increased accumulation of Zn, sometimes twenty times higher than the baseline concentration in the soil [Marguí, et al., 2007]. The results of the content of heavy metals obtained in our studies are comparable with the results in [Popova, 2016].

CONCLUSIONS

The conducted studies allowed us to determine the content of Cr, Co, Ni, Cu, Zn, Ga, As, Y, V, Na, Mg, Si, P, S, K, Ca, Ti, Mn, Fe, S in plants of background sites of oil and gas-bearing regions at the northern part of Western Siberia within the northern taiga, forest tundra and southern tundra. The targets of our research were widely distributed species of tree species (*Betula pubescens, Larix sibirica, Pinus sylvestris*), shrubs *Salix lanata*, suffrutexes (*Vaccinium vitis-idaea, Ledum palustre s. l.*), grasses (*Eriophorum angustifolium, Equisetum arvense*) and lichens (*Cladonia stellaris, Cladonia stygia*). According to the value of a median content in plants, elements are arranged in the following order (mg/kg): Si(8827) > Mg(6469) > Ca(3186) > P(2955) > Mn(752) > S(210) > Ti(137) > Zn(33.9) > Cu(8.3) > Sr(7.0) > Cr(5.3) > Ni(3.4) > Y(2.6) >As(0.47) >V(0.2) > Ga(0.09). It is recommended to use the obtained values of the elements content in vegetation as guide values for the studied territory.

The biological absorption factors of elements in plants are calculated relative to regional baseline concentrations in soils. The maximum coefficients of biological absorption were found for $P_{22.4}$, $Mg_{9.1}$, $Mn_{8.0}$, $Ca_{6.2}$ and Zn1.5. Strong concentration abilities were found in *Equisetum* in terms of potassium content (K_c = 96).

The specific features of chemical elements accumulation in plants have been revealed and the bioclimatic zonation of their accumulation by plants are have been studied. The content of a number of macronutrients (Mg) and minor-nutrient elements (V, Y, As and Co) does not differ statistically significantly among the studied plant species. The greatest difference in the degree of accumulation among the plant species was found for Ni, Zn, Ca, Mn, S and Si.

Statistically significant differences in the accumulation of elements by plants in different bioclimatic zones were found for Cu, Fe, Co, Cr, As, Mg, V, Y. For the remaining elements, the peculiarities of accumulation were not revealed.

REFERENCES

1. Авцын А.П. 1972. Введение в географическую патологию. М.: Медицина. С. 328.
2. Агбалян Е.В., Колесников Р.А., Печкин А.С., Моргун Е.Н., Красненко А.С., Ильясов Р.М., Локтев Р.И., Шинкарук Е.В. 2018. Экологическое состояние почв полигонов комплексного экологического мониторинга «Сабетта», «Харп», «Надымский» Ямало-Ненецкого автономного округа // Научный вестник Ямало-Ненецкого автономного округа. Салехард. №4 (101). С. 5-12.
3. Агбалян Е.В., Шинкарук Е.В. 2015. Уровень химического загрязнения почвы в долине реки Лукыяха Тазовского полуострова // Научный вестник Ямало-Ненецкого автономного округа. №89(4). С. 42-48.
4. Алексеев И.И., Абакумов Е.В. 2019. Тяжелые металлы в почвах природных и урбанизированных ландшафтов Ямало-Ненецкого автономного округа // Научный вестник Ямало-Ненецкого автономного округа. № 1. С. 89-92.
5. Атлас Ямало-Ненецкого автономного округа / Под ред. С.И. Ларин. 2004. Омск. С.304.
6. Байкалова Л.П., Долгова Н.Г. 2018. Кормовые ресурсы и их рациональное использование для оленеводства арктической зоны // Арктика 2018: Международное сотрудничество, экология и безопасность, инновационные технологии и логи-

стика, правовое регулирование, история и современность: материалы международной конференции. Изд-во Красноярский государственный аграрный университет. С. 21-27.

7. Биогеохимические основы экологического нормирования / Под ред. В.Н. Башкина, Е.В. Евстафьевой, В.В. Снакина с соавт. 1993. М.: Наука. С. 304.
8. Битюцкий Н.П. Микроэлементы высших растений. 2011. СПб.: Изд-во СПб гос. у-та. С. 367.
9. Воеводина Л.А., Воеводин О.В. 2015. Магний для почвы и растений. Научный журнал Российского НИИ проблем мелиорации. №2 (18). С. 70-81.
10. Григорьев Н.А. 2009. Распределение химических элементов в верхней части континентальной коры. Екб.: УрО РАН. С. 382.
11. Долгова Л.С., Гаврилова И.П. 1971. Особенности почв средне-и северотаежных подзон Западной Сибири (в пределах Тюменской области) // Природные условия Западной Сибири. М. С. 77.
12. Ермаков В.В., Тютиков С.Ф., Сафонов В.А. 2018. Биогеохимическая индикация микроэлементозов / Под ред. Т.И. Моисеенко. М. С. 386.
13. Журба О. М., Рукавишников В. С., Меринов А. В., Алексеенко, А. Н. 2016. Содержание нефтепродуктов, бенз (а) пирена, тяжелых металлов, мышьяка в почве Ямало-Ненецкого автономного округа и тяжелых металлов, мышьяка в волосах детей // Гигиена и санитария. № 95(6). С. 521-524.
14. Зуев С.М. 2016. Проблемы устойчивого развития оленеводства в ЯНАО// Россия в глобальном мире. № 9 (32). С. 173-187.
15. Иеронова В.В., Безухова, А.В. 2014. Оценка экологического состояния почв в зоне нефтегазодобычи по содержанию загрязняющих веществ (на примере нефтяного месторождения Ямало-Ненецкого автономного округа) // Вестник Югорского государственного университета. №3 (34). С. 38-40.
16. Московченко Д.В., Бабушкин А.Г. 2015. Фоновое содержание подвижных форм металлов в почвах севера Западной Сибири // Вестник Тюменского государственного университета. № 3(3). С. 163-174.
17. Опекунова М.Г. 2013. Диагностика техногенной трансформации ландшафтов на основе биоиндикации: автореф. дис. … докт. геогр. наук. СПб. С. 36.
18. Опекунова М.Г., Опекунов А.Ю., Арестова И.Ю., Кукушкин С.Ю., Спасский В.В., Никитина М.А., Елсукова Е.Ю., Шейнерман Н.А., Недбаев И.С. 2018. Использование методов биоиндикации и биотестирования в оценке экологического состояния территории газоконденсатных месторождений севера Западной Сибири // Вестник Санкт-Петербургского университета. Науки о Земле. Т. 63, №3. С. 326-344.
19. Опекунова М.Г., Опекунов А.Ю., Кукушкин С.Ю., Арестова И.Ю. 2007. Индикаторы антропогенной нагрузки на природно-территориальные комплексы нефтегазоконденсатных месторождений Ямало-Ненецкого автономного округа // Вестник Санкт-Петербургского университета. Науки о Земле. №1. С. 124-127.
20. Опекунова М.Г., Опекунов А.Ю., Кукушкин С.Ю., Ганул А.Г. 2019. Фоновое содержание химических элементов в почвах и донных осадках севера Западной Сибири // Почвоведение. №4. С. 422-439.
21. Позов С.А., Орлова, Н. 2002. Микроэлементозы животных в биогеохимических провинциях. Ставрополь: Saarbrucken. С. 150.
22. Попова Е.И. 2016. Накопление тяжелых металлов фитоценозами Западно-Сибирской Арктики и Субарктики // Современные проблемы науки и образования. №5. С. 317-317.
23. Семенков И.Н. 2019. Интенсивность биогенной аккумуляции тяжелых металлов в системе «почвы-растения» Обь-Пуровского междуречья // Биогеохимия-научная основа устойчивого развития и сохранения здоровья человека. С. 218-221.
24. Скарлыгина-Уфимцева М.Д. 1991. Системно-иерархический анализ микроэлементного состава фитобиоты ландшафтов // Тр. Биогеохимической лаборатории АН СССР. №22. С. 120-134.
25. Скипин Л.Н., Галямов А.А., Гаевая Е.В., Захарова, Е.В. 2016. Экологическая оценка состояния почвенного покрова оленьих пастбищ полуострова Ямал // Вестник Красноярского государственного аграрного университета. №12. С. 194-202.
26. Страховенко В.Д., Щербов Б.Л., Маликова И.Н. 2016. Сравнительный анализ распределения концентраций экологически опасных элементов в компонентах окружающей среды разных ландшафтов Сибири // Экологический мониторинг окружающей среды. С. 123-140.
27. Сысо А.И., Колпащиков Л.А., Ермолов Ю.В., Черевко А.С., Сиромля Т.И. 2014. Элементный химический состав почв и растений Западного Таймыра // Сибирский экологический журнал. Т.21, №6. С. 855-862.
28. Таланов Г.А., Хмелевский Б.Н. 1991. Санитария кормов: справочник. М.: Агропромиздат. С. 303.
29. Тентюков М.П. 2008. Изменение информативности индикационных характеристик тундровых кустарников в условиях аэротехногенного загрязнения // Сибирский экологический журнал. №2. С. 217-224.
30. Томашунас В.М., Абакумов Е.В. 2014. Содержание тяжелых металлов в почвах полуострова Ямал и острова Белый // Гигиена и санитария. №93(6). С. 26-31.
31. Уфимцева М.Д. 2015. Закономерности накопления химических элементов высшими растениями и их реакции в аномальных биогеохимических провинциях // Геохимия. №5. С. 450-450.
32. Шихова Н.С. 2017. Эколого-геохимические особенности растительности южного Приморья и видоспецифичность арборифлоры в накоплении тяжелых металлов // Сибирский лесной журнал. №6. С.76-88.
33. Margun E., Queralt I., Carvalho M. L., Hidalgo M. 2007. Assessment of metal availability to vegetation (Betula pendula) in Pb-Zn ore concentrate residues with different features // Environmental Pollution, 145(1), P. 179-184.
34. Marschner, H. 2011. Mineral nutrition of higher plants / H. Marschner. — 3nd ed. — London. P. 672.
35. White P.J., Broadley M.R. 2003. Calcium in plants // Annals of botany 92(4). P. 487-511.

Received: 13.03.2021
Revised: 15.05.2021
Accepted: 25.06.2021

DOI: https://doi.org/10.17816/edgcc41876

APPENDIX

Table 4

Content of the chemical elements in plants at the Nadymsky region (mg/kg)

CE	Med	M	SD	Norm*	MAL**	Baseline concentrationsinsoils at the YNAO***
V	0.20	0.55	0.72	-	-	27.00
Cr	5.3	5.4	1.7	-	0,5	43.70
Co	0.02	0.17	0.34	0.3-1.0	1,0	4.00
Ni	3.4	3.9	1.7	-	3,0	15.20
Cu	8.8	12.1	14.4	3-12	-	9.95
Zn	34	48	46	20-60	50	23.00
Ga	0.09	0.16	0.17	-	-	-
As	0.47	1.89	2.33	-	0,5	2.00
Y	2.63	14.89	18.12	-	-	6.00
Na	30	44	101	1000	-	1075.25
Mg	6470	6670	2930	1800	-	711.78
Si	8800	10300	7300	10000	-	496139.57
P	2960	2740	903	1500	-	132.0
S	210	790	1030	-	-	-
K	300	5080	9270	3000	-	3654.38
Ca	3190	4670	3370	6000	-	514.00
Ti	137	157	134	-	-	1528.00
Mn	752	877	337	20-60	>500	94.54
Fe	50	188	401	25-50	100	10982.00
Sr	7	15	19	-	-	106.75

CE — chemical element, Med — median value, M — mean value, SD — standard deviate, * normal value according to [Biochemical bases..., 1993], **MAL — maximum allowable limit according to [Talanov, Chmelevsky, 1991]. *** based on the results of analysis of the following papers: [Opekunov et al., 2007; Ieronova et al., 2014; Tomashunas et al., 2014; Agbalyan et al., 2015; Zhurba et al., 2016; Strahovenko et al., 2016; Skipin et al., 2016; Agbalyan et al., 2018; Alekseev et al., 2019; Semenkov, 2019].

DOI: https://doi.org/10.17816/edgcc41876

Table 5

Content of the chemical elements in plants depending on the species (mg/kg)[1]

CE	*Ledum palustre*	*Betula pubescens*	*Vaccinium Vitis-idaea*	*Salix lanata*	*Cladonia stellaris*	*Cladoniastygia*	*Larix sibirica*	*Eriophorum angustifolium*	*Pinus sylvestris*	*Equisetum arvense*
V	0.27	0.10	0.31	0.28	0.09	0.18	0.20	0.19	-	2.25
Cr	5.4	3.3	4.9	3.8	6.1	7.2	5.4	4.1	5.2	4.3
Co	-	-	-	-	0.11	0.19	0.26	-	-	-
Ni	3.3	8.3	3.2	5.5	2.7	2.5	3.1	4.3	4.2	3.4
Cu	10.1	11.1	8.6	11.8	0.4	0.4	14.4	20.9	21.6	15.2
Zn	30	150	32	94	4	4	22	59	57	47
Ga	0.05	0.30	0.09	0.36	-	0.03	-	0.18	0.07	0.32
As	3.29	0.48	3.19	1.91	-	-	3.31	2.49	2.72	0.22
Y	14.2	0.2	24.4	7.2	17.2	2.9	33.3	2.6	18.9	-
Mg	5500	8300	5120	4700	6900	7900	8990	6470	5900	6400
Si	7040	2450	8130	450	13220	13730	8140	9210	6960	24890
P	2780	1940	3210	1890	3240	3250	2990	2680	2790	2150
S	410	800	-	1200	-	-	-	1100	-	3600
K	-	4600	-	10400	-	-	-	3800	-	28793
Ca	2600	5300	3900	11100	2200	2500	3000	2300	2600	10100
Ti	87	188	100	282	251	320	12	199	15	52
Mn	1230	1330	1240	1140	560	590	710	640	890	650
Fe	-	-	-	-	270	425	-	-	-	-
Sr	-	-	-	50	-	-	-	-	-	25

[1] The error bar varied from 5% to 10%.

Table 6

Median content of chemical elements in plants depending on the growing area (mg/kg)

CE	Site № 1	Site № 2	Site № 3
V	<0.09	0.63 0.17-1,28	0.43 0.2-0.77
Cr	6.05 5.4-6.7	4.40 3.7-5.3	5.29 4.4-6.9
Co	-	-	0.07 <0.02-0.37
Ni	3.5 2.7-4.5	3.5 3.2-4.3	3.3 2.7-3.9
Cu	<0.4 <0.4-11.7	14.6 5.6-22.1	8.8 <0.4-15.8
Zn	25 16-52	48 31-78	29 4-49
Ga	0.08 0.03-0.15	0.18 0.03-0.36	0.05 <0.02-0.19
As	-	3.17 0.96-5.71	2.24 <0.02-3.42
Y	-	29.1 <0.02-41.9	16.8 5.7-29.7
Mg	8900 7700-10200	5300 3400-6600	5700 4700-7200
Si	7600 5700-11100	9200 6900-13400	9400 7000-15000
P	2940 2580-3270	2900 2150-3090	2990 2350-3260
S	<200 <200-760	480 <200-1060	<200 <200-1170
K	<300 <300-3900	<300 <300-6500	<300 <300-6300
Ca	3200 2400-4800	3300 2300-6500	3200 2600-5020
Ti	160 20-260	83 12-202	172 59-342
Mn	797 650-1130	740 620-1090	680 590-1150
Fe	-	-	<50 <50-570
Sr	-	<7 <7-11	<7 <7-14

The numerator is a median value of concentration, the denominator is the first and third quartiles

DOI: https://doi.org/10.17816/edgcc41876

Table 7

Coordinates of visited sites

n	place	name	latitude	longitude	n	place	name	latitude	longitude
1	N.taiga	ledum	64.58598	70.94183	37	Forest tundra	lingberry	65.58197	72.11540
2	N.taiga	ledum	64.51162	71.16405	38	Forest tundra	lingberry	65.81552	71.03008
3	N.taiga	ledum	64.52786	72.16885	39	Forest tundra	lingberry	65.75344	75.69913
4	N.taiga	birch	64.56671	70.94138	40	Forest tundra	willow	65.59483	72.00751
5	N.taiga	birch	64.51162	71.16405	41	Forest tundra	willow	65.81552	71.03008
6	N.taiga	birch	64.58751	72.21848	42	Forest tundra	willow	65.74363	75.71055
7	N.taiga	lingberry	64.37391	71.58059	43	Forest tundra	Cladonia stellaris	64.58121	72.20351
8	N.taiga	lingberry	64.37391	71.58059	44	Forest tundra	Cladonia stellaris	65.43226	75.70997
9	N.taiga	lingberry	64.58121	72.20351	45	Forest tundra	Cladonia stellaris	65.74461	75.70997
10	N.taiga	willow	64.50726	71.03552	46	Forest tundra	Cladonia stygia	65.61874	71.88978
11	N.taiga	willow	64.26743	70.9437	47	Forest tundra	Cladonia stygia	65.46921	73.43226
12	N.taiga	willow	64.37391	71.58059	48	Forest tundra	Cladonia stygia	65.82544	75.71075
13	N.taiga	Cladonia stellaris	64.79944	70.94532	49	Forest tundra	larix	65.59483	72.00751
14	N.taiga	Cladonia stellaris	64.48877	71.04145	50	Forest tundra	larix	65.81479	70.99592
15	N.taiga	Cladonia stellaris	64.52836	72.16651	51	Forest tundra	larix	65.74461	75.70997
16	N.taiga	Cladonia stygia	64.58493	70.94532	52	Forest tundra	cotton grass	65.78911	71.53417
17	N.taiga	Cladonia stygia	64.48877	71.04145	53	Forest tundra	cotton grass	65.74567	71.6925
18	N.taiga	Cladonia stygia	64.52786	72.1688	54	Forest tundra	cotton grass	65.82544	75.71075
19	N.taiga	larix	64.56671	70.94138	55	Forest tundra	pine	65.74567	71.20916
20	N.taiga	larix	64.58493	70.94532	56	Forest tundra	pine	65.57803	73.07286
21	N.taiga	larix	64.58121	72.20351	57	Forest tundra	pine	65.71098	74.16663
22	N.taiga	cotton grass	64.51162	71.16405	58	Forest tundra	Equisetum	65.55356	72.24153
23	N.taiga	cotton grass	64.52836	72.16651	59	Forest tundra	Equisetum	65.90652	74.20425
24	N.taiga	cotton grass	64.42165	71.99564	60	Forest tundra	Equisetum	65.90786	75.75230
25	N.taiga	pine	64.58493	70.94532	61	Forest tundra	Equisetum	65.46922	73.43225
26	N.taiga	pine	65.59914	72.22268	62	S.tundra	ledum	65.51944	73.89777
27	N.taiga	pine	64.42056	72.00008	63	S.tundra	ledum	65.63702	74.32866
28	N.taiga	Equisetum	64.50726	71.03552	64	S.tundra	ledum	67.78527	75.48186
29	N.taiga	Equisetum	64.50799	71.03507	65	S.tundra	lingberry	66.48380	73.92025
30	N.taiga	Equisetum	64.37391	71.58059	66	S.tundra	lingberry	65.81552	71.03008
31	Forest tundra	ledum	65.60213	72.00791	67	S.tundra	lingberry	68.04344	75.52311
32	Forest tundra	ledum	65.58197	72.11540	68	S.tundra	willow	65.51944	73.89778
33	Forest tundra	ledum	65.74461	75.70997	69	S.tundra	willow	67.78527	75.48186
34	Forest tundra	birch	65.59972	72.03813	70	S.tundra	willow	68.25058	75.74994
35	Forest tundra	birch	65.55356	72.24153	71	S.tundra	willow	67.91952	74.99752
36	Forest tundra	birch	65.90652	74.20425	72	S.tundra	Cladonia stellaris	66.48380	73.92025

n	place	name	latitude	longitude	n	place	name	latitude	longitude
73	S.tundra	Cladonia stellaris	67.76963	75.54088	82	S.tundra	larix	66.52038	73.89658
74	S.tundra	Cladonia stellaris	68.04344	75.52311	83	S.tundra	larix	67.91952	74.99752
75	S.tundra	Cladonia stellaris	67.91711	75.03992	84	S.tundra	larix	67.89675	75.46627
76	S.tundra	Cladonia stygia	67.74619	75.26992	85	S.tundra	cotton grass	65.51952	73.89583
77	S.tundra	Cladonia stygia	67.74619	75.26992	86	S.tundra	cotton grass	65.63702	74.32861
78	S.tundra	Cladonia stygia	66.48380	73.92025	87	S.tundra	cotton grass	65.81552	71.03008
79	S.tundra	Cladonia stygia	67.76963	75.54088	88	S.tundra	Equisetum	66.51772	73.88197
80	S.tundra	Cladonia stygia	67.97258	75.47141	89	S.tundra	Equisetum	66.31844	73.88186
81	S.tundra	Cladonia stygia	67.91711	75.03991	90	S.tundra	Equisetum	68.24291	75.74708

УДК 551.578.46+551.34+626.876.3
DOI: https://doi.org/10.17816/edgcc21205

IMPACT OF SNOW COVER AND AIR TEMPERATURE ON GROUND FREEZING DEPTH AND STABILITY IN MOUNTAIN AREA

D.M. Frolov

Lomonosov Moscow State University, Moscow, Russia

Corresponding author: e-mail: denisfrolovm@mail.ru

Citation: Frolov D.M. 2020. Impact of snow cover and air temperature on ground freezing depth and stability in mountain area // Environmental dynamics and global climate change. V. 12. N. 1. P. 43–46 . DOI: https://doi.org/10.17816/edgcc21205

Поскольку при строительстве селе- и лавиноудерживающих геотехнических сооружений на горных территориях возникает проблема крепления и устойчивости этих сооружений в условиях сезонного и/или многолетнего промерзания грунта, в данной работе производится оценка влияния снежного покрова и температуры воздуха на глубину промерзания и устойчивость грунта на основе разработанной расчётной схемы за зимние сезоны 2015/16–2019/20 в Приэльбрусье. Расчётная схема строилась на основе задачи теплопроводности трехслойной среды (снег, мерзлый и талый грунт) с фазовым переходом на границе. Уравнение теплового баланса включало энергию фазового перехода, приток тепла из талого грунта и отток в мерзлый грунт и при наличии снежного покрова через него в атмосферу.

Ключевые слова: снежный покров, температура воздуха, промерзание и устойчивость грунта.

ВВЕДЕНИЕ

Одним из факторов устойчивости грунта на склонах при строительстве селе- и лавиноудерживающих геотехнических сооружений в горных территориях является промерзание подстилающего грунта, так как в горных районах грунт может находиться в мерзлом состоянии в течение восьми и более месяцев. Однако, происходящее последнее время изменение температуры воздуха и количества осадков (в первую очередь в виде снега) [Golubev et al., 2008] ведут к изменению глубины и длительности промерзания грунта и как следствие уменьшение его устойчивости. Модельное исследование промерзания грунта в горах производилось в работах [Haberkorn et al., 2016]. В данной работе на основе разработанной расчётной схемы производится оценка глубины промерзания грунта для последних пяти зимних сезонов на основе данных о толщине снежного покрова и температуре воздуха для метеостанции Терскол. Метеостанция Терскол расположена в долине Азау в Приэльбрусье на высоте 2141 м над уровнем моря. Средняя температура января составляет там – °С, июля — 13,4 °С, а средняя сумма отрицательных месячных температур зимнего период (ноябрь-март) составляет –20 °С. За период снегонакопления (в ноябре-марте) выпадает в среднем около 280 мм осадков, вызывая накопление снежного покрова до 70–80 см толщиной. Расчёты изменения глубины промерзания грунта производились по предложенной расчётной схеме по данным о толщине снежного покрова и температуре воздуха на основании трехслойной модели среды (талый грунт, мерзлый грунт, снег) и при предположении линейного изменения температуры в средах и тепловому потоку согласно закону Фурье.

МАТЕРИАЛЫ И МЕТОДЫ

В работе произведены расчёты глубины промерзания грунта на основе данных о температуре воздуха и толщине снежного покрова для метеостанций Терскол за зимние сезоны 2015/16–2019/20 по предложенной в статье [Фролов, 2019] расчётной схеме. Расчётная схема строилась на основе задачи теплопроводности трехслойной среды (снег, мерзлый и талый грунт) с фазовым переходом на границе мерзлого и талого грунта. Расчётная схема применима для условий как покрытой снегом поверхности грунта, так и для оголённой поверхности. Уравнение теплового баланса включало энергию фазового перехода, приток тепла из талого грунта и отток в мерзлый грунт и при наличии снежного покрова через него в атмосферу. Поток тепла рассчитывался по закону Фурье, как произведение теплопроводности и градиента температуры.

Предполагалось, что температура в каждой из сред изменяется линейно (например, [DeGaetano et al., 2001]). Для снежного покрова и мерзлого грунта использовалась формула теплопроводности двухслойной среды.

Расчет промерзания грунта, на основе данных о температуре воздуха и толщине и теплопроводности снежного покрова в течение зимнего периода позволял оценить интенсивность движения фронта промерзания в этот период времени. Зависимость скорости движения фронта промерзания находилась по расчетной схеме. Схема учитывала намерзание грунта снизу на массиве мерзлого грунта в зимний период на основе данных о ежедневной температуре воздуха (и толщине и теплопроводности снежного покрова).

Уравнение теплового баланса на границе фронта промерзания записывалось как $F_1 = cLV + F_2$ или как:

$$dh_{\text{мг}}/d\tau = V = (F_1 - F_2)/cL,$$

где: F_1 — отток тепла через замёрзший грунт (и снежный покров) от фронта промерзания (Вт/м^2) в атмосферу; $LV = cLdh_{\text{мг}}/d\tau$ — расход тепла на фазовый переход, с влагосодержание грунта (1–4 кг/см·м^2, или с долей содержания влаги 0,1–0,4 от общего объёма среды, где максимальное значение содержания влаги, равное 0,4 (которое было принято при расчётах) соответствует полному заполнению пор водой у легкой глины с плотностью 2000 кг/м^3 и коэффициентом пористости 0,617 [Грунтоведение, 2005]); L — энергия фазового перехода (335 кДж/кг), V — скорость движения фронта промерзания (см/с); F_2 — отток тепла на охлаждение талого грунта перед фронтом промерзания (Вт/м^2).

При составлении уравнения баланса тепла было сделано пренебрежение слагаемыми, отвечающими за теплопотери на охлаждение грунта, а также за изменение его влажности с глубиной.

Тепловой поток выражается по закону Фурье через градиент температуры и теплопроводность как $F = -\lambda$ (grad T). Таким образом, тепловой поток от фронта промерзания в атмосферу через комбинацию из двух сред (снег и мерзлый грунт) согласно данным справочника [Михеев, 1977] может быть записан как:

$$F_1 = -\lambda \frac{\Delta T}{\Delta x} = \frac{-\Delta T}{\dfrac{\Delta x_{\text{с}}}{\lambda_{\text{с}}} + \dfrac{\Delta x_{\text{мг}}}{\lambda_{\text{с}}}} = \frac{-T_{\text{возд}}}{\dfrac{h_{\text{с}}}{\lambda_{\text{с}}} + \dfrac{h_{\text{мг}}}{\lambda_{\text{с}}}}$$

здесь $T_{\text{возд}}$ — температура воздуха, $h_{\text{с}}$ и $h_{\text{мг}}$ — толщина снега и глубина промерзания, а $\lambda_{\text{с}}$ и $\lambda_{\text{мг}}$ — теплопроводность снега и мёрзлого грунта.

Предполагалось, что на глубине 10 м в грунте находится точка нулевых годовых колебаний температуры T_0 со значением около 4°C (значение привязывалось к среднегодовой температуре в Терсколе). Поэтому

$$F_2 = -\lambda_{\text{тг}} \frac{\Delta T}{\Delta x} = \lambda_{\text{тг}} \frac{T_0}{10 - h_{\text{мг}}},$$

здесь $\lambda_{\text{тг}}$ — теплопроводность талого грунта. Вычисления производились с шагом в один день. На первый момент предполагалось, что толщина мерзлого грунта $h_{\text{мг}}$ равна 0,5 см. На каждом шаге по времени (каждый день) вычислялась (рассчитывалась) скорость промерзания V и значение толщины мерзлого грунта $h_{\text{мг}}$ для следующего дня (шага по времени). Согласно [Грунтоведение, 2005], средняя теплопроводность талого и мерзлого глинистого грунта может быть взята как 1,4 и 1,8 Вт/м°С.

Средняя теплопроводность снега $\lambda_{\text{с}}$ рассчитывалась относительно плотности по формуле А.В. Павлова [Павлов, 1979] и бралась равной 0,18 Вт/м°С.

РЕЗУЛЬТАТЫ РАСЧЁТОВ И ОБСУЖДЕНИЕ

В работе для выведенного дифференциального уравнения по времени первого порядка для изменения глубины промерзания грунта была построена разностная схема посредством аппроксимации этого дифференциального уравнения явным методом Эйлер: $h_{\text{мг}}(t_{\text{n+1}}) = h_{\text{мг}}(t_{\text{n}}) + \Delta t V(t_{\text{n}})$. По полученной разностной схеме для каждого зимнего сезона 2015/16–2019/20 были произведены расчёты изменения глубины промерзания грунта. Результаты расчётов приведены на рис. 1.

Примененный метод расчёта является хорошо физически обоснованным. Решение по методу хорошо описывает процесс изменения глубины промерзания в течение зимнего сезона. Важным для успешной работы метода является наиболее возможно точное задание начальных данных.

Результаты расчета максимальной глубины промерзания грунта для метеостанции Терскол за зимние периоды 2015/16–2019/20 приведены в таблице 1.

Согласно расчётам, грунт под снежным покровом остается мёрзлым в Приэльбрусье с декабря по апрель. Мощность накапливаемого снежного покрова может достигать при этом полуметра и более. При этом грунт под покрытой снежным покровом поверхностью промерзает согласно расчётам в среднем на 20 и более сантиметров. В случае частичного или полного

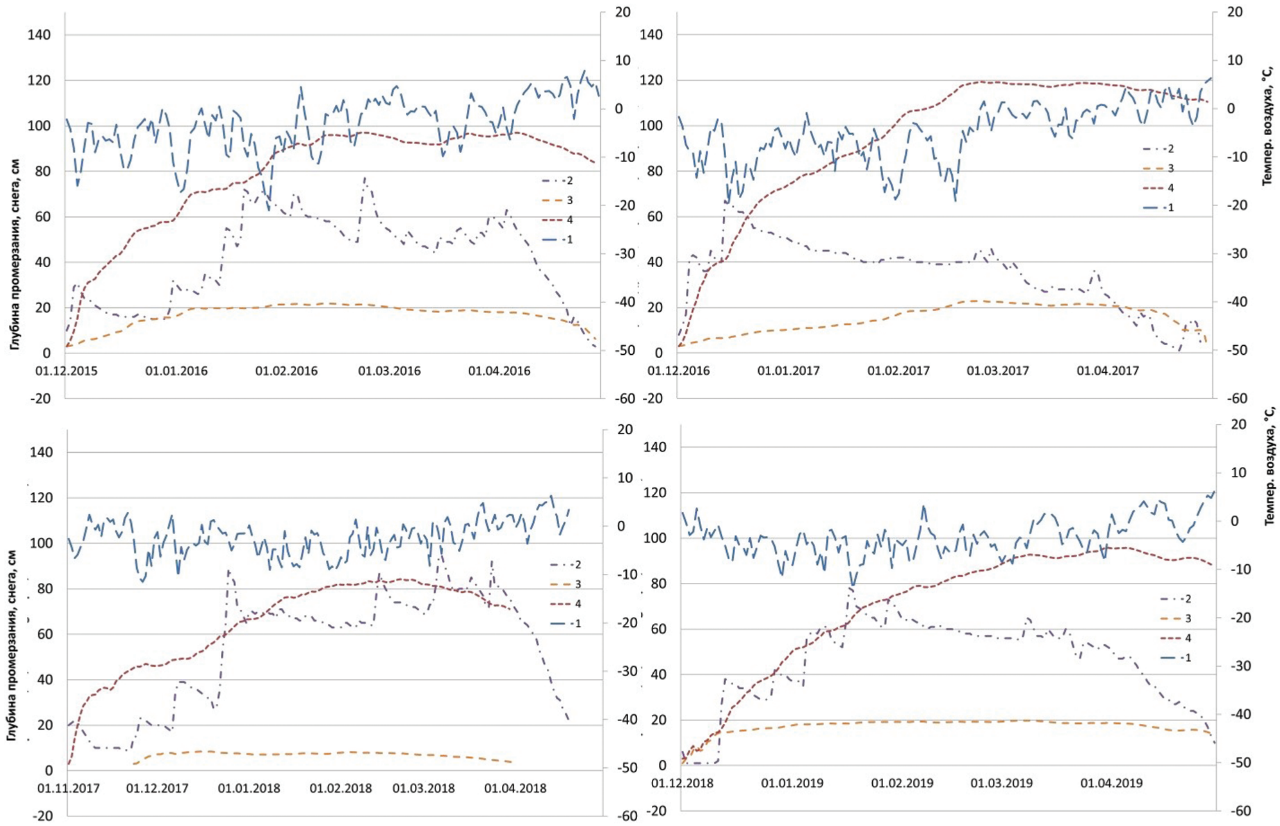


Рис. 1. Изменения температуры воздуха и глубины промерзания по данным расчётов для покрытой снегом и оголённой поверхности грунта для метеостанции Терскол для зимних периодов 2015/16—2018/19 (1 — температура воздуха, 2 — толщина снежного покрова и 3 — расчётная глубина промерзания грунта под снежным покровом 4 — расчётная глубина промерзания оголённого грунта)

Таблица 1

Изменение максимальной глубины промерзания грунта, средней за февраль толщины снежного покрова и суммы отрицательных среднемесячных температур для метеостанции Терскол за зимние периоды 2015/16–2019/20

Зимний период	Сумма отриц. среднемес. температур, °C	Сред. за февраль толщина снежного покрова, см	Макс. глубина промерзания покрытого снегом грунта, см	Макс. глубина промерзания оголённого грунта, см
2015/16	–18,7	60	21	97
2016/17	–27,7	40	23	119
2017/18	–14,2	70	8	83
2018/19	–19,4	60	20	96
2019/20			20	

сдувания снежного покрова промерзание грунта может происходить на глубину до 1 метра и более и длиться более продолжительный период. Таким образом, предложенный метод расчёта динамики глубины промерзания грунта на основе данных о температуре воздуха и толщине снежного покрова позволяет оценить промерзание грунта как фактора устойчивости грунта при строительстве селе- и лавинозащитных сооружений.

Работа выполнена на основе темы I.7 АААА-А16-116032810093-2 «Картографирование, моделирование и оценка риска опасных природных процессов» (ГЗ).

ЛИТЕРАТУРА

1. Грунтоведение / Под ред. В.Т. Трофимов. 2005. М.: Изд-во Наука. С. 1024.
2. Кудрявцев В.А. 1954. Температура верхних горизонтов вечномерзлой толщи в пределах СССР. М.: Изд-во АН СССР. С. 183.
3. Михеев М.А. 1977. Основы теплопередачи / Под. Ред. М.А. Михеев, И.М. Михеева. М.: Изд-во Энергия С. 344.

4. Павлов А.В. 1979. Теплофизика ландшафтов. Новосибирск.: Изд-во Наука. С. 284.
5. Фролов Д.М. 2019. Расчёт глубины промерзания грунта под оголённой и покрытой снегом поверхностью на метеостанции МГУ за зимние периоды 2011/12-2017/18 // Динамика окружающей среды и глобальные изменения климата. Т. 10. № 2. С. 86-90.
6. DeGaetano A.T., Cameron M.D., Wilks D.S. 2001. Physical simulation of maximum seasonal soil freezing depth in the United States using routine weather observations // Journal of Applied Meteorology. Vol. 40(3). P. 546–555.
7. Golubev V.N., Petrushina M.N., Frolov D.M. 2008. Winter regime of temperature and precipitation as a factor of snow-cover distribution and its stratigraphy // Annals of Glaciology Vol. 49, P. 179-186.
8. Haberkorn A., Wever N., Hoelzle M., Phillips M., Kenner R., Bavay M., Lehning M. 2016. Distributed snow and rock temperature modeling in steep rock walls using Alpine3D // The Cryosphere Discuss. DOI: https://doi.org/10.5194/tc-2016-73

Received: 19.04.2021
Revised: 15.05.2021
Accepted: 20.06.2021