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Assessment of the state of soils in specially protected natural reservations of the Kirov region

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The assessment of the state of the specially protected natural areas (SPNA) of the regional (the "Pizhemsky" zakaznik) and of the federal significance (the "Nurgush" nature reserve) located in the Kirov region is given in the article. The predominant type of soils of the SPNRs under the study is alluvial turf soils, with strongly and slightly acidic reaction of the medium. The content of organic matter in the soils of the "Pizhemsky" zakaznik varies from 3.1 to 4.7% for meadow and from 1.2 to 7.3% for forest phytocenoses. For the territory of the "Nurgush" nature reserve the content of organic matter in the soils of forest phytocenoses ranges from 2.0 to 6.7%. The content of nitrate nitrogen in the soils of the studied SPNR corresponds to the average level of soil supply with nitrogen. A decrease in the content of ammonium nitrogen down the soil profile was noted for the studied sites. The content in the soils of heavy metals (Zn, Mn, Fe, Cu, Pb, Cd) is at a stable level within the ecological norm. In all studied soil samples, the main content of metals was manganese and iron, both for active and for gross form. The maximum content of active forms of manganese and iron is found in soil samples of the upper horizons. Insignificant amounts of copper, lead and cadmium indicate the absence of man-caused contamination of the soil in these sites. Among the gross forms of heavy metals, iron predomination in soil samples of the upper and lower horizons was recorded. The maximum content of gross iron form was noted in the samples from the territory of the "Nurgush" nature reserve.

Keywords: the Kirov Region, the "Pizhemsky" zakaznik, the "Nurgush" nature reserve, soils, agrochemical properties, heavy metals, ecosystem.

Оценка состояния почв особо охраняемых природных территорий Кировской области

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Проведена оценка состояния особо охраняемых природных территорий (ООПТ) регионального – заказник «Пижемский» и федерального значения – заповедник «Нургуш», распложенных в Кировской области. Преобладающим типом почв исследуемых ООПТ является аллювиальные дерновые почвы, с сильно- и слабокислой реакцией среды. Содержание органического вещества в почвах территории заказника «Пижемский» варьирует от 3,1 до 4,7% для луговых и от 1,2 до 7,3% для лесных фитоценозов. Для территории заповедника «Нургуш» содержание органического вещества в почвах лесных фитоценозов изменяется в интервале от 2,0 до 6,7%. Содержание нитратного азота в почвах исследуемых ООПТ соответствует среднему уровню обеспеченности почв азотом. Для исследуемых территорий отмечено снижение содержания аммонийного азота вниз по почвенному профилю. Содержание в почвах тяжёлых металлов (Zn, Mn, Fe, Cu, Pb, Cd) находится на стабильном уровне в пределах экологической нормы. Во всех изучаемых почвенных образцах основной вклад в содержание металлов вносят марганец и железо, как для подвижной, так и для валовой формы. Максимальное содержание подвижных форм марганца и железа установлено в образцах почв верхних горизонтов. Незначительные количества меди, свинца и кадмия свидетельствуют об отсутствии техногенного загрязнения почвы на этих участках. Среди валовых форм тяжёлых металлов отмечено преобладание железа в пробах почвы из верхнего и нижнего горизонтов. Максимальное содержание валовой формы железа было отмечено в образцах с территории заповедника «Нургуш».

Ключевые слова: Кировская область, заказник «Пижемский», заповедник «Нургуш», почвы, агрохимические свойства, тяжёлые металлы, экосистема.

The creation of specially protected natural areas (SPNA) is an effective measure to maintain the ecological balance of the territories, as well as the restoration of natural ecosystems. The main task of the existing SPNA is the preservation of biological and landscape diversity in all its forms. Currently, the total area of protected territories in the world is more than 4 million km^2, of which Russian areas account for 1 million 950 thousand km^2, which is 11.5% of the country's territory [1].

Despite the high value, SPNA can change under the influence of both anthropogenic and natural factors; the loss of their ecological significance is also possible [2]. To foresee negative changes and define environmental measures aimed at optimizing the state of protected reservations is possible through environmental monitoring of natural environments and objects.

The soil, among the objects of the natural environment, is of particular importance. As a complex polyfunctional natural system it has a significant impact on the Earth's ecosystems and the biosphere as a whole [3]. In relation to the environment the soil performs an important protective function. According to the modern ecological concept, pollution of the soil is any action that causes violation of its normal functioning. Soil contaminants can be any physical agents, chemicals in different aggregate states, biological species that enter the soil or appear in it in quantities that go beyond their background concentration. Concentrating on the surface of the soil all these can worsen the general properties of the soil [4].

Despite the exclusion of the possibility of direct contamination of the SPNA soil due to the absence of anthropogenic activity, indirect contamination due to the translocation of substances with air masses and with water during floods is possible.

The purpose of this work was to assess the state of the soils of the specially protected natural reservations of regional (the "Pizhemsky" zakaznik) and of the federal significance (the "Nurgush" nature reserve) located in the Kirov region. In accordance with the Russian environmental legislation, "Nurgush" refers to the "zapovednik" type territories, and "Pizhemsky" – to the "zakaznik" type.

Earlier researches of soils of studied SPNA were carried out mainly in the context of forest vegetation researches, botanical researches, as well as studies of invertebrate and vertebrate fauna [5]. The results of this work can be used in studying and assessing the degree of degradation of similar soils of cross-border areas. The obtained materials can serve as a basis for monitoring studies in the territories of the "Nurgush" nature reserve and the "Pizhemsky" zakaznik.

Objects and methods

The objects of the study were the soils of two nature protected areas located in the Kirov region: the "Pizhemsky" zakaznik and the "Nurgush" nature reserve.

The state nature zakaznik (SNZ) "Pizhemsky", established to protect and restore aquatic biogeocenoses, is located on the lands of the Arbazhsky, Kotelnichsky, Pizhansky, Tuzhinsky and Sovetsky districts of the Kirov region. The territory of the reserve has an elongated form from the north-west to the south-east along the Pizhma River downstream with a turn to the south-east along the Nemda River, flowing into the Pizhma River. The area of the reserve is 30847.94 hectares. The most part of the reserve

Table 1

Characteristics of sampling sites and soil types (A1)

Protected territories	No. of sampling site	Type of phytocenosis	Type of soil
The "Pizhemsky" zakaznik	1	meadow	alluvial turf granular medium-loamy medium-humus
	4		
	2	forest	alluvial turf granular medium-loamy medium-humus
	3		alluvial turf granular heavy-loamy humus-rich dark-humus
	5		alluvial turf light-loamy medium-humus
	6		alluvial turf light-(medium)-loamy medium-humus
	7		alluvial turf sandy-loam low-humus
The "Nurgush" nature reserve	8	forest	alluvial turf
	9		
	10		

is located within the Kotelnichskaya lowland, which is a flat sandy lowland with a few shallow and low uplifts overlain by cover loams [6].

The state nature reserve (SNR) "Nurgush" is the only nature reserve in the territory of the Kirov region. It is located in the south-eastern part of the Kotelnichsky district. The reserve was created to protect the floodplain complexes of the Vyatka River – numerous lakes and coniferous-broadleaf forests. The territory of the reserve is composed of modern alluvial sediments. Soils are heterogeneous in the granulometric state. The predominant types of soils are alluvial turf soils [7].

Sampling of the soil for the research in the "Pizhemsky" zakaznik was carried out on sites located along the Pizhma River (No. 1, 4 – meadow, and 2, 3, 5, 6, 7 – forest phytocenoses) (Fig. 1, see color insert).

In the state reserve "Nurgush" sampling of the soil was carried out on the sites of forest phytocoenoses located on the shores of lakes Chernoye, Nurgush, Krivoye (sites No.No. 8, 9, 10) (Fig. 2, see color insert).

Sampling was carried out from the upper horizons of the soil from a depth of 0–10; 10–25 cm, including the thickness of the sod in meadow and litter in forest phytocenoses in the summer period (2017 July–August). The description of sampling sites is presented in Table 1.

In the soil samples the reaction of soil extract was determined by a potentiometric method in accordance with GOST 26483-85; the content of organic matter – according to the Tyurin's method in the modification of CINAO; nitrate and ammonium nitrogen – by the method of CINAO; labile phosphorus – by Kirsanov's method in the modification of CINAO. The content of active and gross forms of heavy metals was determined by the method of atomic absorption spectroscopy.

Statistical processing of the research results was carried out by standard statistical analysis methods using EXCEL.

Results of the study and their discussion

The study of the reaction of the soils extracts in the territory of the "Pizhemsky" reserve showed that the soils are slightly-, medium- and strongly acidic (Table 2). The values of exchange acidity in the experimental samples taken from the upper horizons of the soil (0–10 cm) varied from 5.0 to 5.5 for meadow and from 4.4 to 5.6 for forest phytocenoses.

For most of the sites studied, there was observed a tendency to decrease acidity from the upper to the lower horizon, except for sites No. 1 and No. 7. In contrast to the territory of the "Pizhemsky" zakaznik, the soils of the territory of the "Nurgush" nature reserve are characterized by a more acid reaction of soil extract (4.1–4.9) and are strongly and slightly acidic. The determined values of exchange acidity for SPNA soils were characteristic of alluvial turf soils.

The content of organic matter in the samples taken from the upper horizons of the soils in the "Pizhemsky" zakaznik was higher in forest (11.9–21.3) than meadow (9.3–11.5) phytocenoses, which is associated with higher incidence of plant litter in forest than meadow phytocenoses. It is known that in forest litter the accumulation of biogenic carbon can reach 43% of the mass [8]. In comparison with the upper horizon, the soils of the lower horizon were characterized by a lower content of organic matter. The determined values of organic matter content in the

soil varied from 3.1 to 4.7 for meadow and from 1.17 to 7.3 for forest phytocenoses. Among the sites studied, sites No. 2 and No. 7 under forest phytocenoses had the highest content of organic matter. The soils of the lower horizon (depth 10–25 cm) were distinguished by high (site No. 3), medium (sites No. 4, No. 5), low (sites No. 1, No. 6, No. 2) and very low (site No. 7) content of organic matte. The obtained results are understandable, since the distribution of organic carbon down the profile sharply decreases.

For the territory of the "Nurgush" nature reserve, the content of organic matter in the upper horizons soils changed in a narrower range (from 2.0 to 6.7%). In general, the soils of the "Nurgush" nature reserve were characterized by low (No. 10), medium (No. 9) and high levels of organic matter (No. 8).

The content of nitrate and ammonium nitrogen in the soils of the studied sites varied widely. Relative evenness of the values of nitrate nitrogen in the soil (17.3–19.5 mg/kg) was distinguished in the sites located in the territory of the "Nurgush" nature reserve. The content of nitrate nitrogen there corresponded to the average level of nitrogen in soils for plants (15–20 mg/kg). The content of ammonium nitrogen was lower than that of nitrate, and varied from 6.3 to 11.4 mg/kg.

In contrast to the "Nurgush" nature reserve, in samples taken from the upper horizons of the soils in the "Pizhemsky" zakaznik the prevalence of ammonium nitrogen over the nitrate was noted for most of the sites studied with the exception of sites No. 4 and No. 3. The content of nitrate nitrogen in the upper horizons of meadow soil phytocenoses corresponded to the average level of provision of soils with nitrogen for plants (15–20 mg/kg), the content of nitrate nitrogen in the upper horizons of forest soil phytocenoses – very low level of provision (site No. 2), medium level (site No. 5), high level of provision for plants (site No.No. 3, 6, 7). In comparison with the upper horizons (8.1–18.4 mg/kg), of forest phytocoenosis downward along the profile, an increase in the content of nitrate nitrogen (17.8–23.7 mg/kg) was noted downward along the profile in the soils of forest phytocoenoses, except for site No. 3. For this site the highest content of nitrate nitrogen (62.4 mg/kg) was

Table 2

Agrochemical characteristics of the soils in the studied sites

Site	Horizon, cm	pH*$_{KCl}$	Organic matter, %	N – NH_4^+, mg/kg	N – NO_3^-, mg/kg	P_2O_5, mg/kg
Soils under meadow phytocenosis. The "Pizhemsky" zakaznik						
1	0–10	5.0	9.3±0.9	7.2±1.2	16.4±3.3	37 ± 7
	10–25	5.3	3.1±0.5	15.1±2.9	20.1±4.0	7.3 ± 2.6
4	0–10	5.5	11.5±1.2	34.5±1.7	17.7±3.5	11.0 ± 3.9
	10–25	5.2	4.7±0.7	3.2±0.1	16.3±3.3	ND
Soils under forest phytocenosis. The "Pizhemsky" zakaznik						
5	0–10	4.8	12.0±1.2	16.3±1.8	10.9±2.2	ND
	10–25	4.6	4.3±0.6	21.0±1.1	23.4±4.7	ND
6	0–10	4.5	11.9±1.2	58.9±2.9	14.9±2.3	ND
	10–25	4.0	2.3±0.5	23.1±1.2	24±5	ND
2	0–10	5.4	20.3±2.0	47.0±4.0	8.1±2.4	37 ± 7
	10–25	4.6	2.6±0.5	17.6±0.9	17.8±3.6	ND
3	0–10	5.6	12.9±1.3	40.1±2.0	63±13	8.5 ± 3.0
	10–25	5.2	7.3±0.7	14.9±0.7	12.4±2.5	ND
7	0–10	4.4	21.3±2.1	94±5	18.4±3.7	ND
	10–25	4.5	1.17±0.23	76.5±3.8	22±4	40 ± 8
Soils under forest phytocenosis. The "Nurgush" nature reserve						
8	0–10	4.1	6.7±0.7	11.4±3.6	18.3±3.7	ND
9	0–10	4.8	4.2±0.6	6.3±1.1	17.3±3.5	ND
10	0–10	4.9	2.0±0.4	9.8±2.6	19.5±3.9	ND

*Note: * Acidity measurements are performed with the deviation of the results of repeated measurements from the arithmetic mean no more than 0.1 pH, ND – not detected (below the detection limit of the method used).*

observed against the backdrop of the least acid reaction of salt extract from the soil.

The content of ammonium nitrogen in the upper soil horizons of meadow phytocoenoses of the "Pizhemsky" zakaznik varied from 7.2 to 34.5 mg/kg, of forest phytocoenoses – from 16.3 to 94 mg/kg. In contrast to nitrate nitrogen, a decrease in the content of ammonium nitrogen down the soil profile was noted for all the sites of forest phytocenoses under the study.

The content of active phosphorus in the soil samples of the studied sites varied greatly. In most soil samples the content of active phosphorus was below the detection limit of the method. The only exceptions were sites No. 1 and No. 4 under meadow phytocenoses, sites No. 2 and No. 3 under forest phytocenoses located in the territory of the "Pizhemsky" zakaznik. Moreover, the maximum content of active phosphorus in the profile of the soils of the studied sites was in the upper horizons. With an increase in the depth of the soil profile, a gradual decrease in the content of active phosphorus was observed. The exception was site No. 7, where the content of active phosphorus was maximal in the lower horizon and amounted to 40 mg/kg. Such an uneven distribution of phosphorus along the soil profile may be due to the heterogeneity of the granulometric composition of the soil-forming materials [9].

The samples of soils were characterized by different contents of heavy metals, which depended both on the location of soil sampling and on the horizon. However, it can be noted that among the studied metals in all soil samples manganese and iron were the main elements. This applies to both the active and the gross form of these metals (Table 3, 4). The content of the active form of iron in the samples varied from 5.3 to 318 mg/kg, and its gross form varied from 667 mg/kg to 26.3 g/kg. The content of the active form of manganese varied from 12 to 486 mg/kg, and the content of the gross form of this element in soil samples varied from 29 to 1295 mg/kg. The content of zinc in soil samples was smaller and amounted from 2.4 to 21 mg/kg in its active form, and from 20 to 84 mg/kg in its gross form. Other detectable heavy metals

Table 3

The content of the active form of heavy metals in the studied soil samples, depending on the location of the site and the depth of the horizon

Site	Horizon, cm	Content of heavy metals in the explored soils, mg/kg					
		Zn	Mn	Fe	Cu	Pb	Cd
The "Pizhemsky" zakaznik							
1	0–20	10.6±3.5	91±33	**320±80**	0.160±0.013	0.80±0.11	0.090±0.009
	20–25	4.9±1.6	47±17	132±33	0.300±0.024	1.49±0.12	0.095±0.010
2	0–5	12±4	120±40	5.3±1.3	0.050±0.004	1.72±0.14	0.070±0.007
	20–25	2.4±0.8	14±5	32±8	0.175±0.014	1.310±0.025	0.030±0.003
3	0–5	21±7	**490±180**	86±22	0.095±0.008	0.69±0.09	0.230±0.018
	20–25	**10.9±3.6**	63±23	190±50	0.170±0.014	0.72±0.10	0.115±0.012
4	0–5	10.8±3.6	260±90	**280±70**	0.360±0.029	1.02±0.08	**0.195±0.020**
	20–25	4.9±1.6	96±34	180±50	0.340±0.027	0.88±0.12	0.130±0.013
5	0–5	9.5±3.1	170±60	68±17	**1.28±0.08**	1.62±0.13	0.110±0.011
	20–25	3.4±1.1	9.0±3.2	200±50	0.17±0.014	1.24±0.10	0.060±0.006
6	0–5	2.5±0.8	190±70	39±10	0.030±0.002	2.10±0.16	0.120±0.012
	20–25	2.0±0.7	32±12	150±40	0.185±0.015	1.10±0.09	0.060±0.006
7	0–5	17±6	279±100	11.0±2.8	0.090±0.007	**2.27±0.18**	0.080±0.008
	20–25	3.6±1.2	19±7	45±15	0.185±0.015	1.39±0.11	0.040±0.004
The "Nurgush" nature reserve							
8	0–10	9.3±3.1	111±40	145±36	0.51±0.031	0.66±0.09	**0.195±0.020**
9	0–10	4.8±1.6	78±28	180±40	0.285±0.023	0.93±0.13	0.150±0.015
10	0–10	3.3±1.1	12±4	74±19	0.56±0.04	0.75±0.10	0.040±0.004
MPC	–	23	–	–	3	6	–

Note: the maximum values of an index are noted in bold. A dash means an absence of the approved standard.

Table 4

The content of the gross form of heavy metals in the studied soil samples, depending on the location of the site and the depth of the horizon

Site	Horizon, cm	Content of heavy metals in the explored soils, mg/kg					
		Zn	Mn	Fe	Cu	Pb	Cd
The "Pizhemsky" zakaznik							
1	0–20	57±19	480±110	13300±3300	9.7±2.2	3.9±0.8	0.27±0.07
	20–25	29±10	96±22	3700±900	9.4±2.2	5.5±1.1	0.24±0.06
2	0–5	26±8	105±24	670±170	2.1±0.5	5.8±1.2	0.25±0.06
	20–25	24±8	126±29	2800±700	1.69±0.39	2.8±0.6	0.115±0.035
3	0–5	50±16	500±110	5300±1300	9.5±2.2	8.3±1.7	0.47±0.12
	20–25	54±18	780±180	13800±3500	11.3±2.6	7.6±1.6	0.26±0.06
4	0–5	28±9	200±50	12700±3200	15.8±3.6	8.3±1.7	0.36±0.08
	20–25	42±14	530±120	6000±1500	13.3±3.1	10.1±2.1	0.27±0.07
5	0–5	29±9	210±50	6000±1500	4.9±1.1	6.3±1.3	0.34±0.08
	20–25	20±6	29±7	3400±900	3.5±0.8	3.8±0.8	0.15±0.05
6	0–5	18±6	230±50	2700±700	4.6±1.1	10.1±2.1	0.24±0.06
	20–25	33±11	305±70	9900±2600	7.6±1.8	5.2±1.1	0.15±0.04
7	0–5	45±15	370±90	1900±500	2.8±0.6	**13.1±2.8**	0.20±0.05
	20–25	39±13	196±45	5200±1300	3.0±0.7	2.6±0.6	0.080±0.024
The "Nurgush" nature reserve							
8	0–10	**84±28**	**1300±300**	24028±6000	**25±6**	8.6±1.8	0.34±0.08
9	0–10	63±21	1100±240	**26000±7000**	14.9±3.4	8.0±1.7	0.22±0.05
10	0–10	23±8	170±40	5400±1300	12.1±2.8	5.2±1.1	0.13±0.04
MPC	–	100	1500	–	55	32	0.5

Note: the maximum values of an index are noted in bold. A dash means an absence of the approved standard.

such as copper, lead and cadmium were in the soil in small quantities, which indicates that there is no man-caused contamination of the soil in these sites.

For undisturbed natural soils, the most important factor determining the content of heavy metals is their content in the soil-forming material [10–12]. Most of the examined soil samples belonged to alluvial turf soils formed on modern alluvial sediments. Alluvial acidic soils are characterized by intensive alluvial process with deposition of a large amount of alluvium of light granulometric composition and flooding with fast flowing flood waters for a short time [13]. Modern alluvial deposits are characterized by an increased content of active Fe, Mn, Zn [14].

The highest content of active forms of manganese and iron was noted in soil samples of the upper horizons (Table 3). The maximum content of active manganese was noted in sample No. 3 from the territory of the "Pizhemsky" zakaznik, collected in the oak forest. The maximum content of the active form of iron was noted for the sites No. 1 and No. 4 of the "Pizhemsky" zakaznik, both of these sites belong to meadow phytocenoses.

The obtained results are in agreement with the previously known ones [15] on the distribution of heavy metals in the soils of the North-east of the European part of Russia. It was noted that modern alluvial deposits in this region are characterized by an increased content of active forms of iron, manganese and zinc [16].

When determining the gross content of heavy metals in soil samples, the predominance of iron was noted, for which high values were observed both in soil samples from the upper horizon and in samples of soil selected lower along the profile (Table 4).

The maximum content of gross iron form was noted in sites No. 8 and No. 9 taken in the territory of the "Nurgush" nature reserve and it amounted to 24000 and 26300 mg/kg respectively. In the same samples, the maximum content of the gross form of manganese and zinc among the samples studied was noted. In sample No. 8, the manganese content was 1300 mg/kg, and the zink

content was 84 mg/kg, which exceed the percent abundance of these elements in the lithosphere.

Conclusion

Thus, as the result of the conducted studies it is established.

1. The soils of the SPNA studied were characterized as strongly and slightly acidic. At the same time, the soils in the territory of the "Nurgush" state nature reserve were characterized by a more acid reaction of the soil extract.

2. The determined values of organic matter for the soils of the "Pizhemsky" zakaznik varied from 3.1 to 4.7% for meadow and from 1.17 to 7.3% for forest phytocenoses. For the territory of the "Nurgush" state nature reserve the content of organic matter in the soils of the studied sites varied within a narrower range.

3. The content of nitrate nitrogen in the soils of the territory of the "Nurgush" nature reserve corresponded to the average level of nitrogen in soils for plants. A decrease in the content of ammonium nitrogen down the soil profile was noted for all the sites of forest phytocenoses under the study.

4. Among the metals studied, in both active and gross form, in all soil samples, the main content was elements such as manganese and iron. The highest content of active forms of manganese and iron was noted in soil samples of the upper horizons. Insignificant amounts of copper, lead and cadmium indicate the absence of man-caused contamination of the soil in these sites. Among the gross forms of metals, iron predominates in soil samples from the upper and lower horizons were stated. The maximum content of gross iron form was noted in the samples taken in the territory of the "Nurgush" nature reserve.

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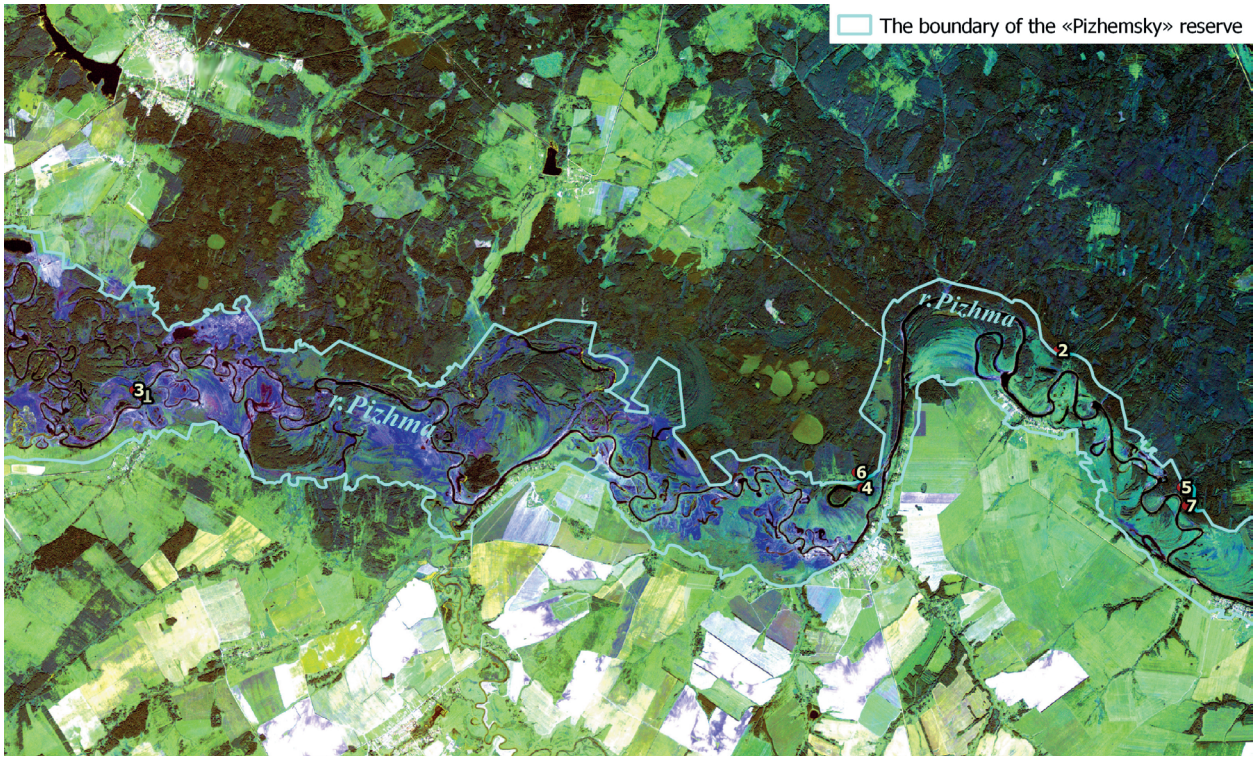

Fig. 1. The map of soil sampling sites in the territory of the "Pizhemsky" reserve

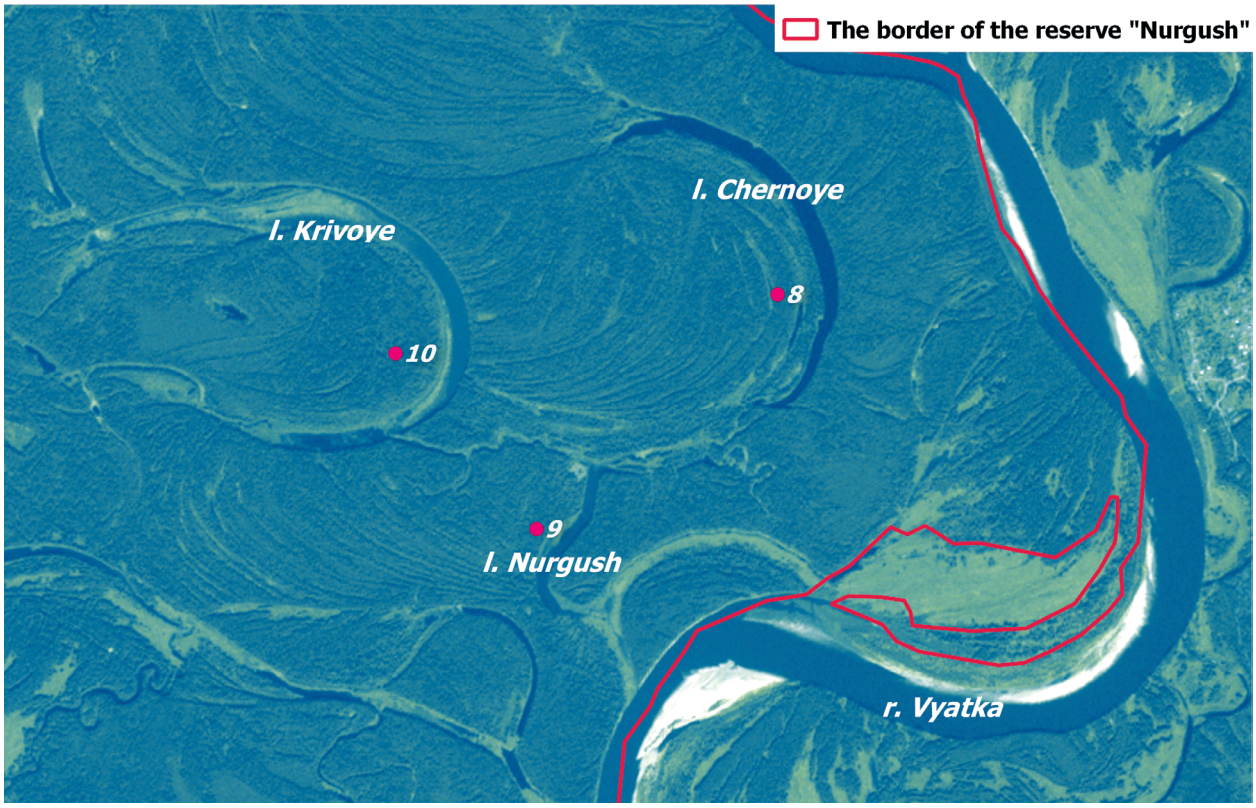

Fig. 2. The map of soil sampling sites in the territory of the reserve "Nurgush"