ECOSYSTEMS: ECOLOGY AND DYNAMICS, 2021, Vol. 5, No. 1, pp. 94-112

DYNAMICS OF ECOSYSTEMS AND THEIR COMPONENTS

UDC 550.43

AEROSOL INFLOW OF INDUSTRIAL POLLUTANTS INTO THE ENVIRONMENTAL COMPONENTS OF THE CENTRAL KOLA IMPACTED REGION

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Received February 20, 2020. After revision March 01, 2021. Accepted March 01, 2021.

The Kola Peninsula is one of the most explored arctic regions of Russia. It has been undergoing an intense industrial development for more than 80 years. The proximity of industrial objects that caused negative changes of different severity in the natural landscapes of the territory, along with the morphological changes of geosytems of various ranks led to formation of impacted regions. One of those regions is the Central Kol, located in the center of the peninsula near Monchegorsk and Kirovsk cities, where the industrial impact is caused by the non-ferrous metals facility “Severonikel”, part of the “Kola Mining and Metallurgical Company” and mining company “Apatit”. Over the past 20 years the negative condition of the local geosystems was partially restored by the “Kola Mining and Metallurgical Company” which took measures for manufacturing modernization and reclamation of the disturbed natural territories. It is necessary to assess these measures as the key ones for the restoration of ecological prosperity of the studied region. For this work we used literary sources, regional reviews of the natural environment condition, our own field materials and some earlier studies carried out by the Department of Environmental Management, Geographical Faculty of the Moscow State University in the central part of the Kola Peninsula. We used a number of methods, such as bioindication of atmospheric pollution (lichen- and bryo-indication), comparative-geographical method, cartographical method, geochemical method and mathematical method. During the study we identified some zones in the central part of the peninsula, where the sources of industrial air pollutants affected the environmental components. Our study showed that natural ecosystems tended to self-restore in the impacted regions due to the decreasing emissions and manufacturing modernization.

Keywords: Kola Peninsula, Khibiny Mountains, Monchegorsk, “Severonikel”, “Apatit”, bioindication, heavy metals, strontium, sulfur compounds.

DOI: 10.24411/2542-2006-2021-10079

In the past decade the problems of natural environment condition in the Russian part of Arctic have become highly important due to the big economic, social and ecological roles of the region. At the moment Murmansk Oblast is the most developed region of the Russian Arctic. Therefore, the problems of the impact caused by industrial pollutants in its territory are very relevant.

The industrial impact in the central part of the Kola Peninsula (Fig. 1) has formed the Central Kola impact region (Evseev, Krasovskaya, 1996), where the current main emission sources are “Severonikel” factory (Photo 1) of the “Kola Mining and Metallurgical Company” and “Apatit” mining company.

The territory around the “Severonikel” is an industrial wasteland, which has formed during the long functioning of its facilities. The prevailing components in the atmospheric emissions from the “Severonikel” are sulfur compounds and ferrous aerosols (Dushkova, Evseev, 2010).

In the region of mining and enrichment of apatite-nephelite ores in the Khibiny Mountains the landscape is not as intensely deserted as it is in the proximity of the non-ferrous metals facilities. However, the soils and rock formations are mechanically disturbed due to the quarries mining and other activities. The territory is severely dusted, and strontium concentrations are very high in the air, soils and vegetation (Evseev, Krasovskaya, 1990).

It should be noted that the impact of the facilities of such scale are extremely critical for these forest-tundra and northern taiga landscapes of the studied territory, because their assimilative potential and self-restoration ability are too low. Therefore, the territory within dozens of kilometers around the "Severonikel" facility represents a typical impact region; its vegetation and land covers are partially degraded, and the depositing environments accumulate pollutions (Evseev, Krasovskaya, 1997).

In the past few years this problem has been partially solved by the "Kola Mining and Metallurgical Company" which took measures to modernize its production and reclaim damaged natural areas. It is necessary to assess these measures as the key ones for the restoration of ecological prosperity of the studied region, which makes this study very relevant.

The aim of our work was to determine the areas of the main industrial pollutants distribution, released during the operation of the large manufacturing facilities in the studied territory.

Materials and Methods

The most significant changes in the natural environment, including those that led to the formation of an industrial wasteland, were registered near the non-ferrous metals enterprise.

To carry out the study we selected a transect that ran along the valley of Imandra Lake to the north and south from the "Severonikel" to determine the boundaries of the impact area. It was 40 km long, and more than 20 sampling plots were created. Moreover, for further comparison the samples were taken near Kandalaksha town, Umba village, Teriberka settlement and in the Khibiny Mountains, in the area of mining and enrichment of apatite-nephelite ores. The plots for mosses, lichens and soils sampling are shown in the Figures 2-4.

The locations of sampling plots were determined by distribution of anthropogenic pollutants due to the direction of predominant winds. We also assessed the impact of orographic factor. The sampling plots were located according to the current Guidance Document No. 52.44.2-94 (1994); therefore the samples were collected along the main points of the compass 1, 2, 5, 10, 15, 20, 30 and 40 km away from the pollution sources. The samples were also collected in the spots of geoecological monitoring, which had been previously made by the employees of the Department of Environmental Management, and out of the 40 km zone.

During this study we analyzed fund and literary sources, and took the samples which then were processed to determine the distribution of industrial air pollutants and compare the obtained information with the already existing data. Our work was carried out in 3 steps: preparation, field studies, laboratory processing of the samples.

To analyze the distribution of air pollutants over the studied territory we used bioindication methods (bryo-indication and lichen-indication). These methods are applied to analyze the content of pollutants in mosses and lichens. The various reactions of mosses and lichens to the impact of pollutants allow us to use them as bioindicators-monitors. We selected individual species of mosses and lichens (Sphagnum sp., Cladonia sp.) that were widely represented in the area and supported mainly by the atmospheric nutrition.

When studying lichens, their biological reactions to anthropogenic impact are very clear. Their main feature is a high sensitivity to changes in the chemical composition of atmospheric air. Lichens accumulate heavy metals and other toxicants from the air, and are used to determine the emissions patterns and location of pollution sources (Opekunova, 2016).

Bryophytes and lichens share some features, such as small size, usually perennial development cycle, ecological and physiological characteristics. Unlike the lichens, the structure of mosses is hydrophytic and highly absorbing; therefore this type of mosses accumulates more pollutants than the ones with xerophytic structure (Chernenkova, 2002).

Bioindicators allow us to make a spatial picture of pollutants accumulation both in the region and individual territories. This method is widely used in Scandinavia (Chernenkova, 2002).

Fig. 1. Location of the study area (Topographic Map …, 2019).

Photo 1. View of the “Severonikel” facilities in Monchegorsk (Photo by Kh.S. Sultygova).

The result of our studies, carried out in the central part of the Kola Peninsula, determined the background values of heavy metals and strontium in mosses (*Sphagnum* sp.) and lichens (*Cladonia* sp.), which are presented in Tables 1-3.

Every sample was cleaned, dried and its species composition was determined, then they were processed by the method of atomic-absorptive spectrometry with fire automation. The determination error of this method ranges from 15 to 30% (Mitsyk et al., 1990).

To determine the presence of sulfur compounds in the soil cover we used the German method which requires the application of butanol and potassium thiocyanate (KCNS). We already successfully used this method in the same region (Yevseev, Krasovskaya 1996). The color saturation determined the presence of sulfur compounds (8 ppm deep red was a high indicator). The measuring results are shown in Table 4 and were used to create a corresponding map (Fig. 11, 12).

This data was used both in its original form and in calculations of geochemical coefficients. They were used to calculate the concentration coefficient (Kc). Based on the analysis results, the concentration coefficient maps were compiled. The obtained data was compared with the background values of heavy metals and strontium accumulation.

Results and Discussion

We focused on the effect that the non-ferrous metal facility had on the components of natural environment; sulfur dioxide and heavy metals (Cu and Ni) were dominant in its emissions. Recently the volumes of emissions during the production modernization have significantly decreased to 50 thousand tons per year. The emissions of sulfur dioxide have dropped the most. On the basis of obtained data, we compiled the maps of concentration coefficient for nickel and copper (Fig. 5-10) in the lichen- and bryo-indicators. The content of sulfur dioxide in the upper soil horizon (ppm) is shown in the Figures 11 and 12.

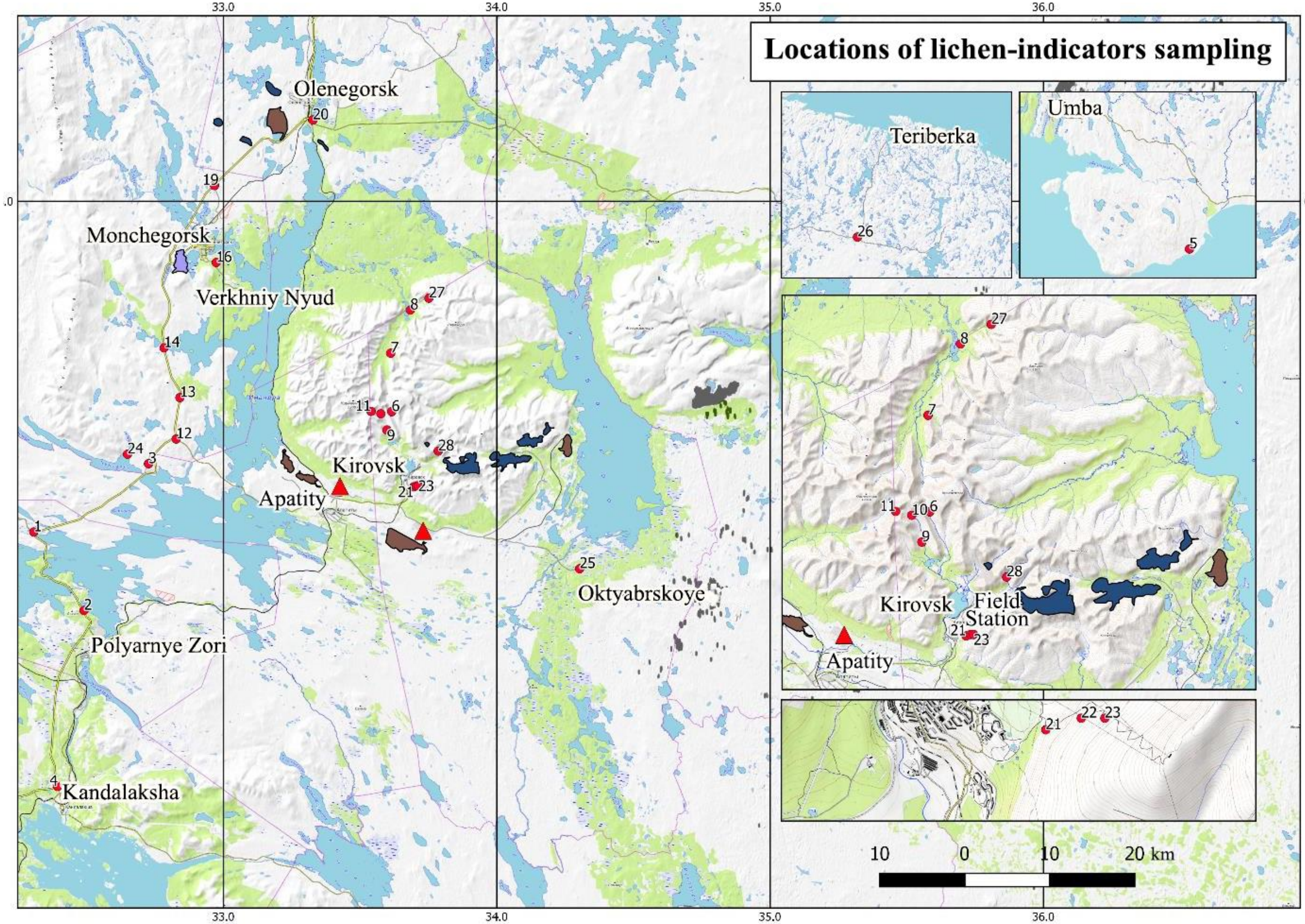

Fig. 2. Locations of lichen-indicators sampling.

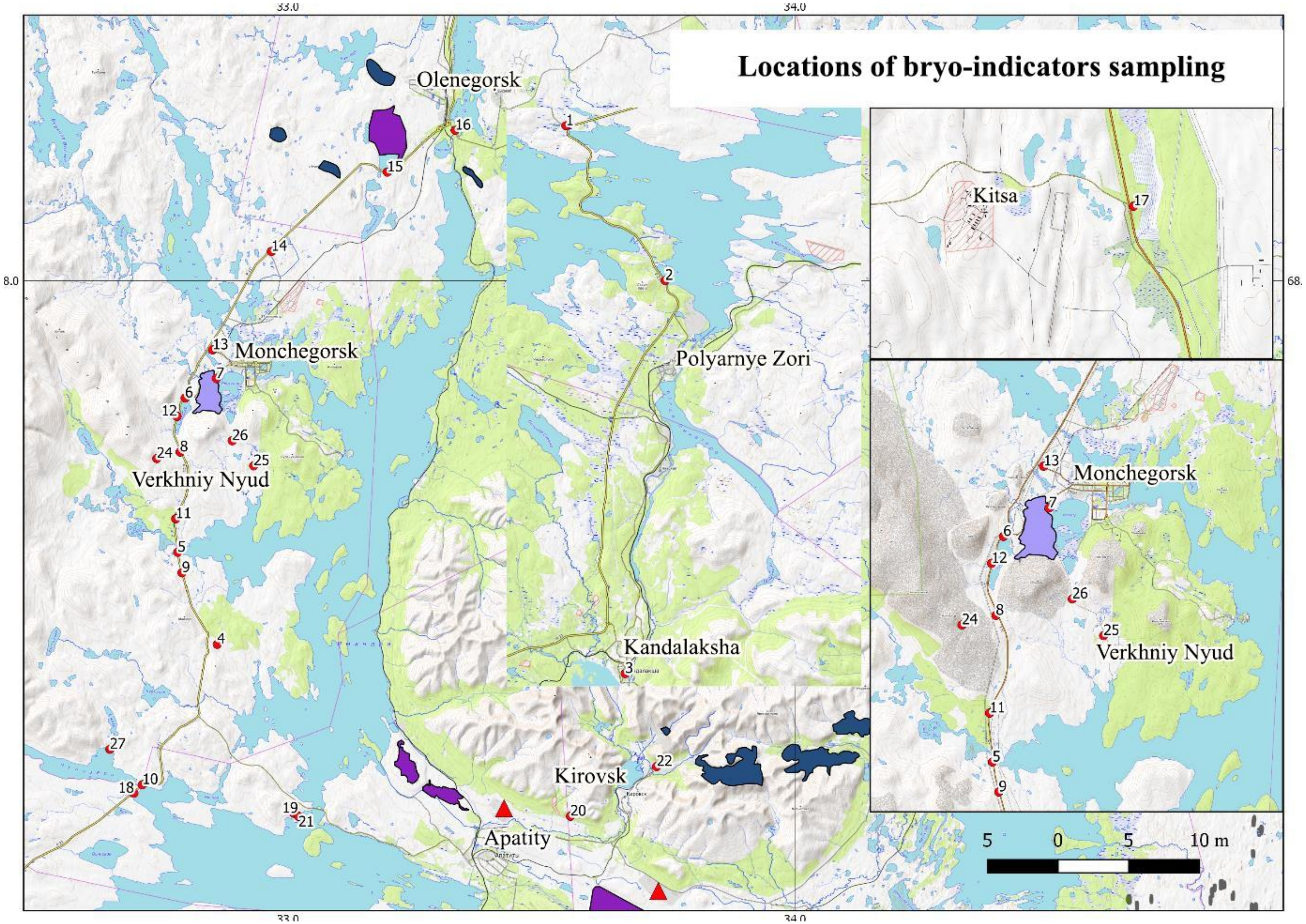

Fig. 3. Locations of bryo-indicators sampling.

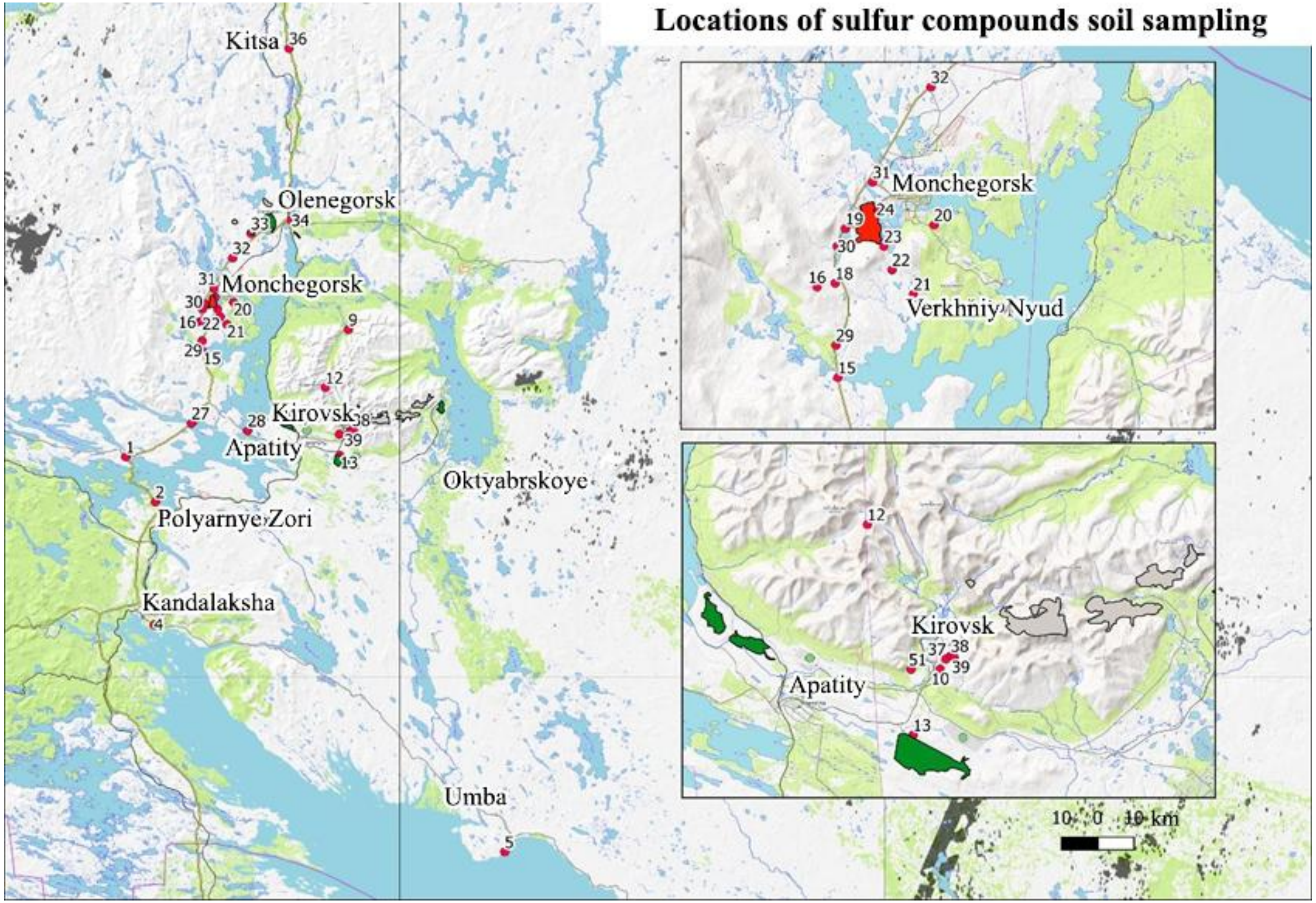

Fig. 4. Locations of upper horizon soil sampling.

Table 1. Background concentrations of heavy metals and strontium in Cladonia sp. and Sphagnum sp., mg/kg.

	Geographic Coordinates		Cu	Ni	Sr
	X_TYPE	Y_TYPE			
Cladonia sp.	34.302484° L	67.491418° N	1	0.3	0.9
Sphagnum sp.			2.5	2	7.6

Table 2. Chemical components content in the lichen samples, mg/kg.

№	Cu	Ni	Sr
1	4.7	3.6	0.2
2	2.5	2.8	4
3	6.8	10.5	1.1
4	1.9	2	0.4
5	1	0.6	0.4
6	4.7	3.6	0.2
7	2.5	2.8	4
8	3.9	2.8	2.8
9	2.9	2.6	17.8
10	3	1.9	20.2
11	2.5	3.7	59.3
12	21.5	16.3	0.3
13	39.4	49.8	0.2
14	55.2	46.7	0.2
15	21.7	52.3	3.6
16	39.4	42.5	0.5
17	6.6	3.7	0.9
18	2.1	1	1.2
19	1.6	2	15
20	1.4	0.8	18.1
21	25.3	21.6	0.1
22	1	0.3	0.9
23	1.5	0.6	0.3
24	3.4	7.4	11.8
25	1.9	0.8	16.4
26	27.2	50.5	4.8
27	58	55	1.4

Table 3. Chemical components content in the moss samples, mg/kg.

№	Cu	Ni	Sr
1	2.9	3.1	4.3
2	5.2	5.4	8
3	3.2	4.5	5.3
4	8.6	9.1	4.3
5	4.7	9.6	6
6	615	900	1.5
7	565	286	3.2
8	240	463	3
9	3.1	11.1	4.7
10	6.2	9.1	10
11	2.6	2.5	6
12	876	1680	22
13	2450	1060	1.6
14	27.3	73	4.6
15	4.5	9.6	5.8
16	3.6	5.2	4.7
17	2.40	1.80	4.50
18	5.6	7.2	6.5
19	8.7	8.7	6.6
20	76.6	160	1.8
21	6.7	13.1	7.2
22	4.4	2.3	14.8
23	3	2.3	5.2
24	284	277	11.7
25	38.4	39	23.6
26	16.1	280	0.6
27	16.4	26.1	1.4

In the 40 km area around the “Severonikel” the elliptical zones of changes in the natural geosystems can be found. In the proximity of the facility (3-5 km) there is an anthropogenic wasteland, where the natural vegetation cover (northern taiga) is completely destroyed, the soils are strongly degraded (horizon B emerges to the surface), and the differences between the altitude zones of the nearby tunturi-ridges are erased. The mosses and lichens are absent in this zone. Only the degraded sphagnum peat bogs were found there, with extremely high content of nickel (Kc>150) and copper (Kc>20). The copper and nickel excess in the bryo-indicators was higher than 200. An excess of sulfur in the upper soil horizon of the studied zone was between 4 and 7 ppm. Currently, the birch and spruce undergrowth begins to appear in the landscape depressions, which can be associated with a sharp reduction of industrial air emissions from the facilities.

In the area of progressing changes (5-10 km) the trees appear, such as willows, birches and coniferous species. The ground vegetation cover is closed, but lacks the species which are sensitive to pollution (blueberries, lichens, sphagnum). The needles and leaves of tree species are affected by necrosis, the deadwood rate is increased, and the undergrowth is weak. We registered an increased content of copper (Kc up to 113.6) and nickel (Kc up to 168.3) in our samples. The concentration coefficient in the bryo-indicators was 113 and 138 for copper and nickel respectively, and no more than 4 for strontium. It should be noted that the concentration of sulfur dioxide was from 3 to 7 ppm on the sampling sites 10 km from the factory. Outside that 10 km zone the spots with sulfur compound content higher than 2.5 ppm were rare.

Table 4. Sulfur content in the upper soil horizon, ppm.

№	ppm	№	ppm
1	<2.5	16	<2.5
2	<2.5	17	<2.5
3	<2.5	18	<2.5
4	3	19	2.7
5	6	20	<2.5
6	<2.5	21	3.5
7	3	22	5
8	<2.5	23	<2.5
9	<2.5	24	4.5
10	4	25	<2.5
11	2.6	26	2.7
12	<2.5	27	<2.5
13	<2.5	28	<2.5
14	4	29	<2.5
15	7	30	2.7

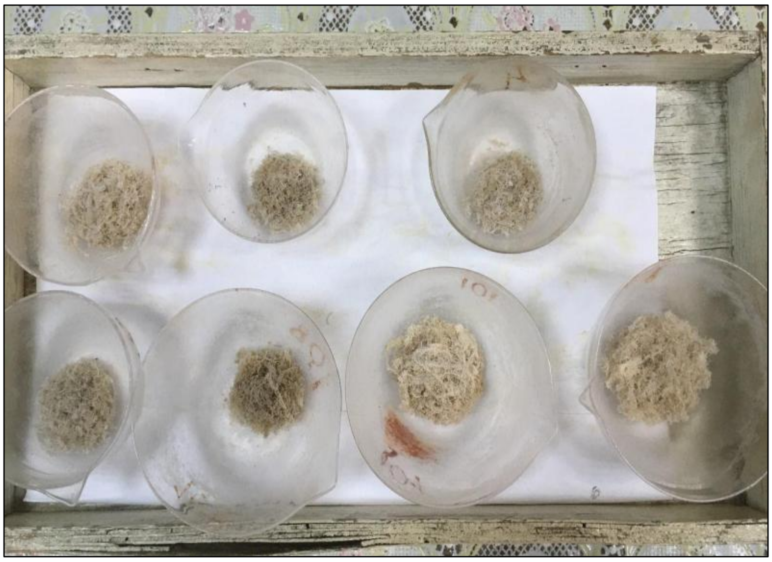

Photo 2. Ashing of the moss and lichen samples (Photo by Kh.S. Sultygova).

In the area of moderate changes (10-25 km) the lichen-moss cover has recovered. However, the signs of the impact caused by the “Severonikel” facility on the ecosystem, such as dry tree tops, chlorosis, necrosis, were also registered. In the area of initial changes (25 km and further) the dry tops and other signs of negative impact are rare at the moment.Kc in the lichen-indicators was 2-10, i.e. low.

The concentration coefficient of elements according to the bryo-indicators was from 1.2 to 7. In the area 30 km to the north of the “Severonickel” factory the concentration coefficient in lichen-

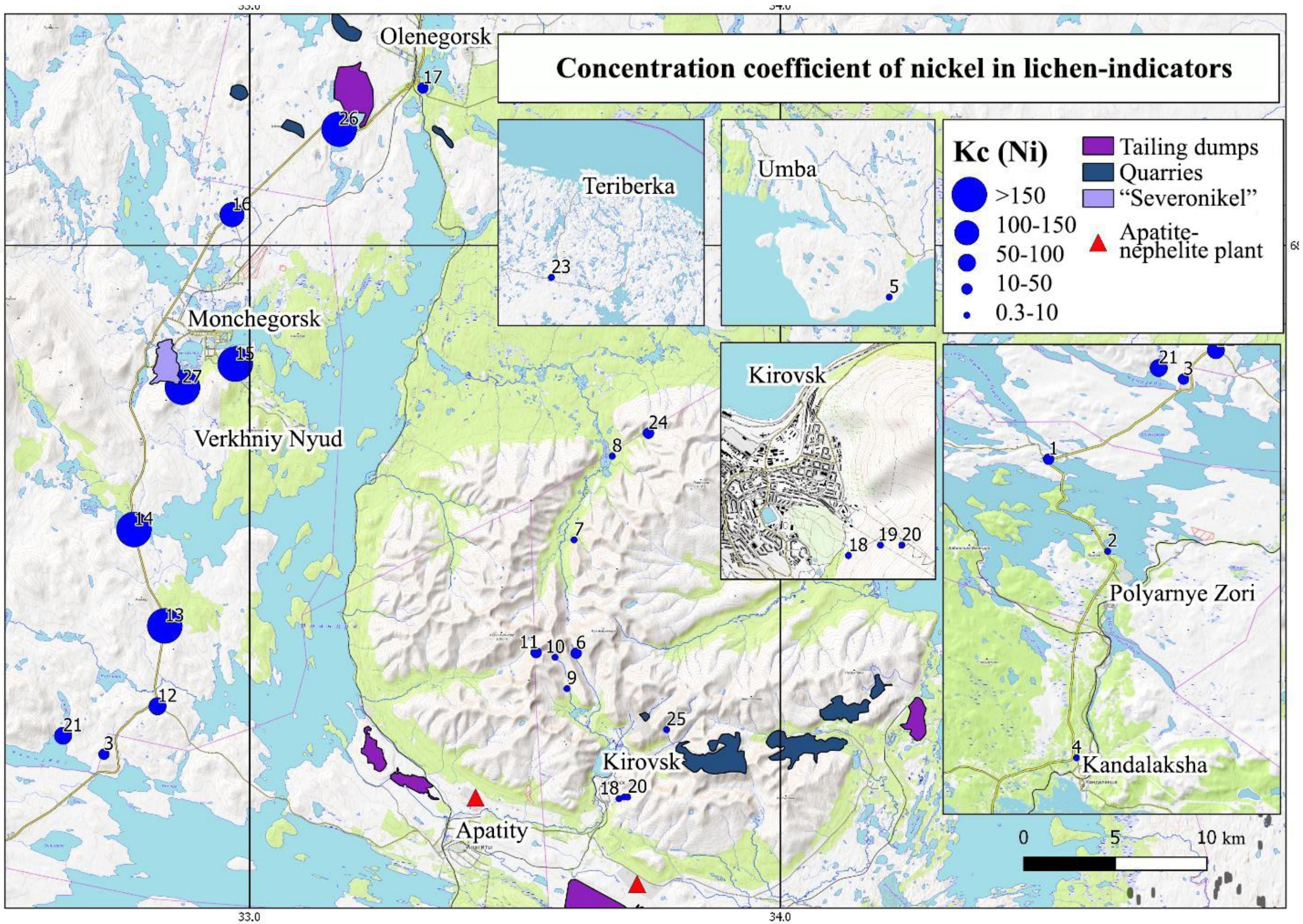

Fig. 5. Concentration coefficient of nickel in lichen-indicators.

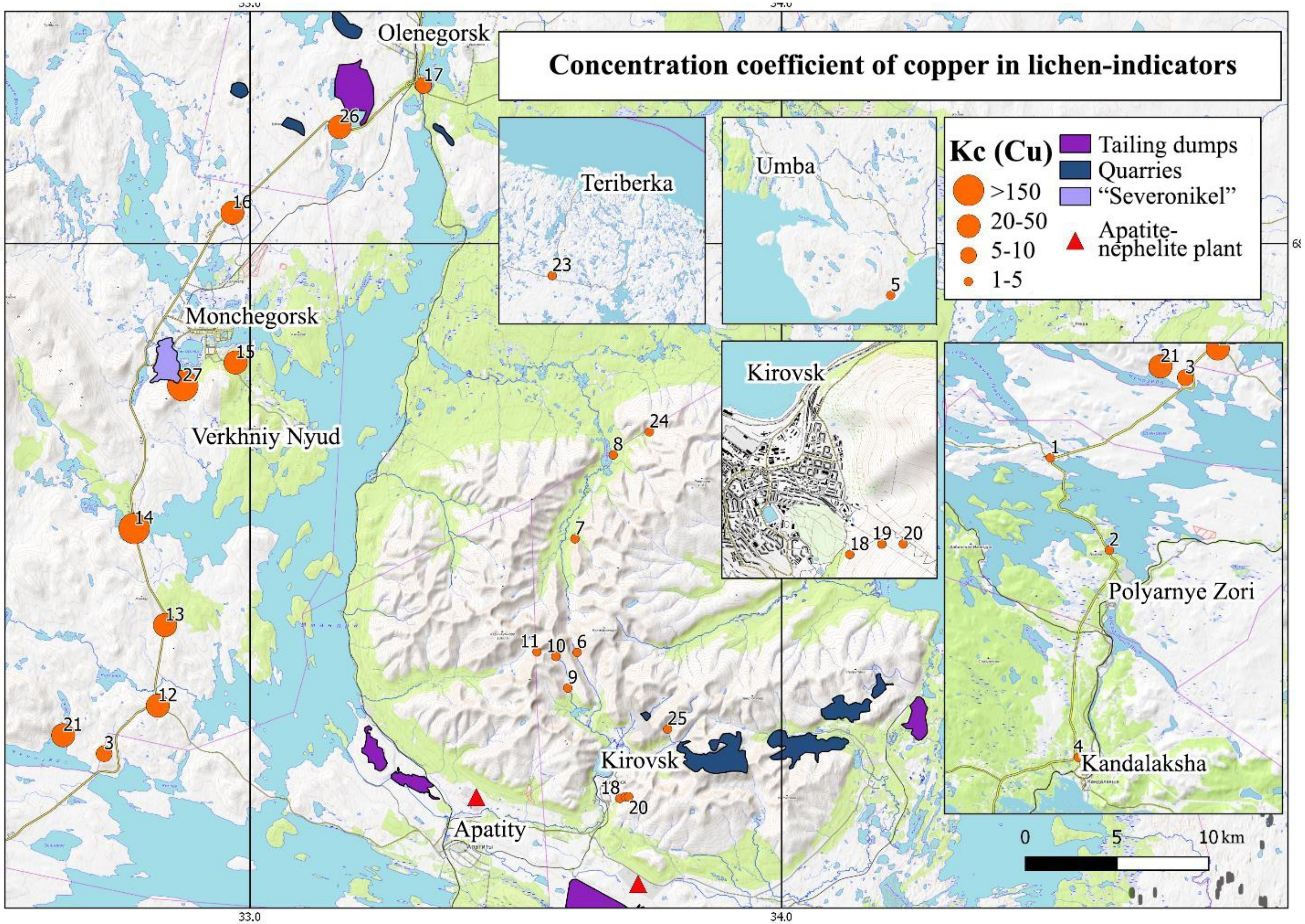

Fig. 6. Concentration coefficient of copper in lichen-indicators.

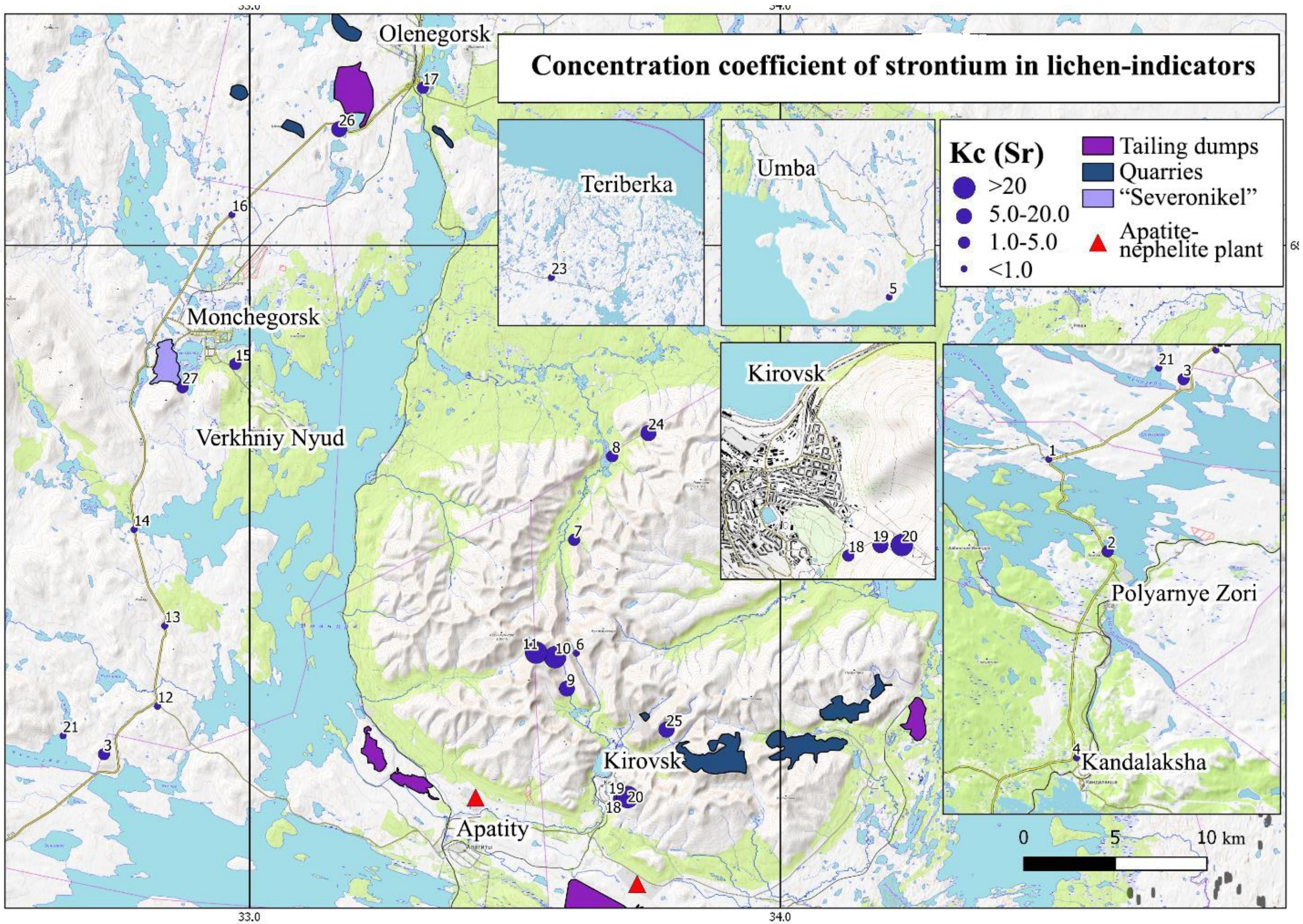

Fig. 7. Concentration coefficient of strontium in lichen-indicators.

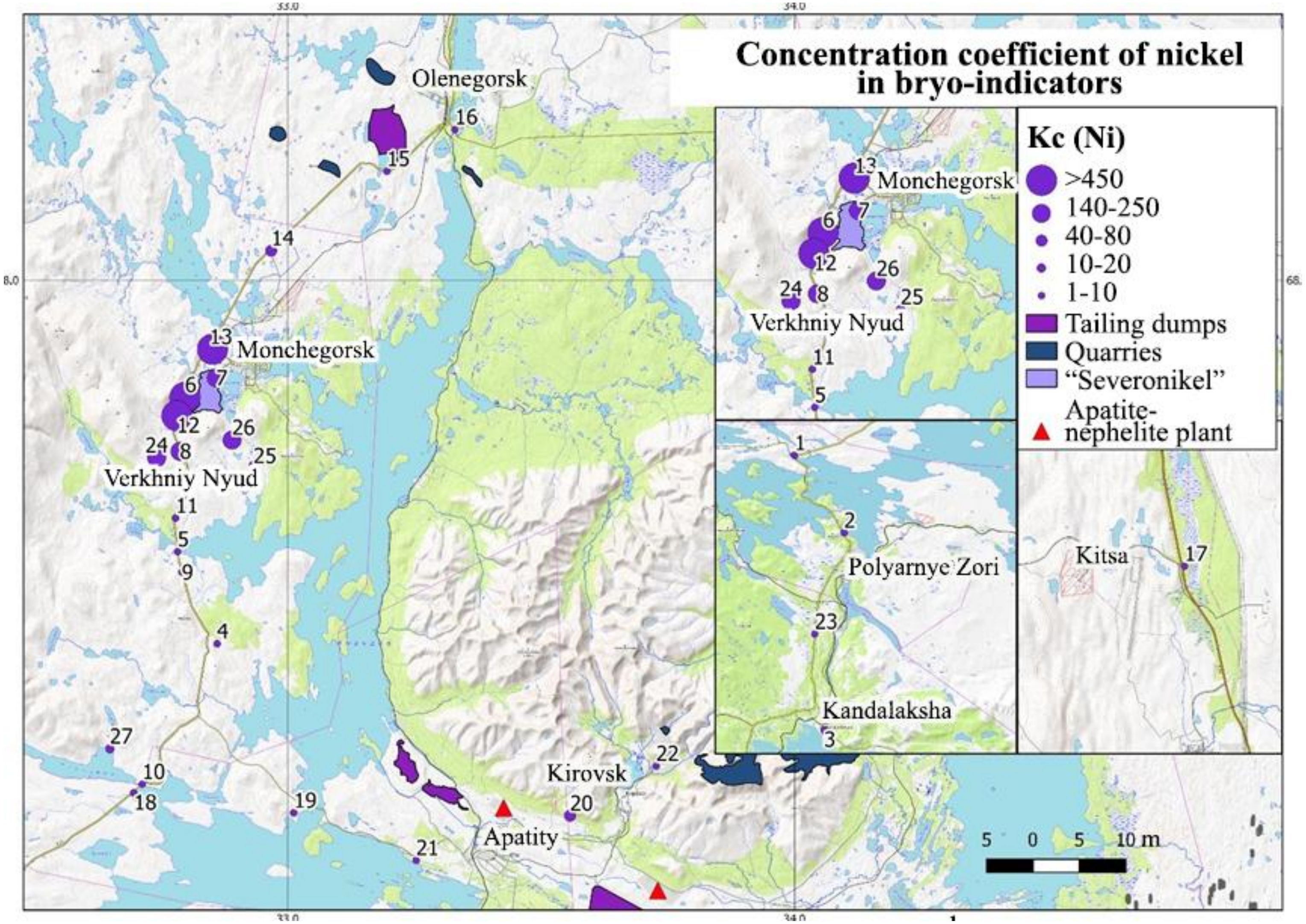

Fig. 8. Concentration coefficient of nickel in bryo-indicators.

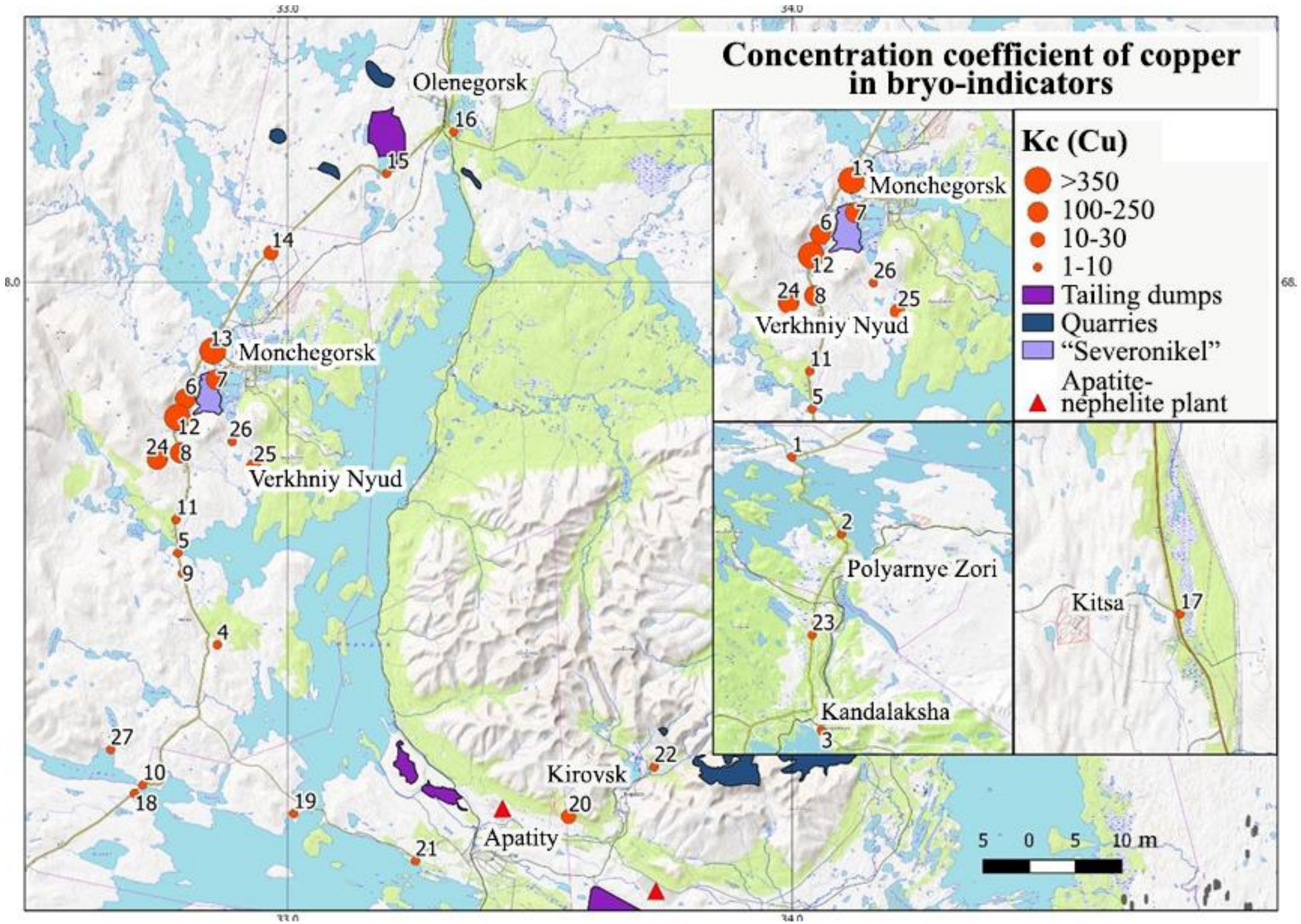

Fig. 9. Concentration coefficient of copper in bryo-indicators.

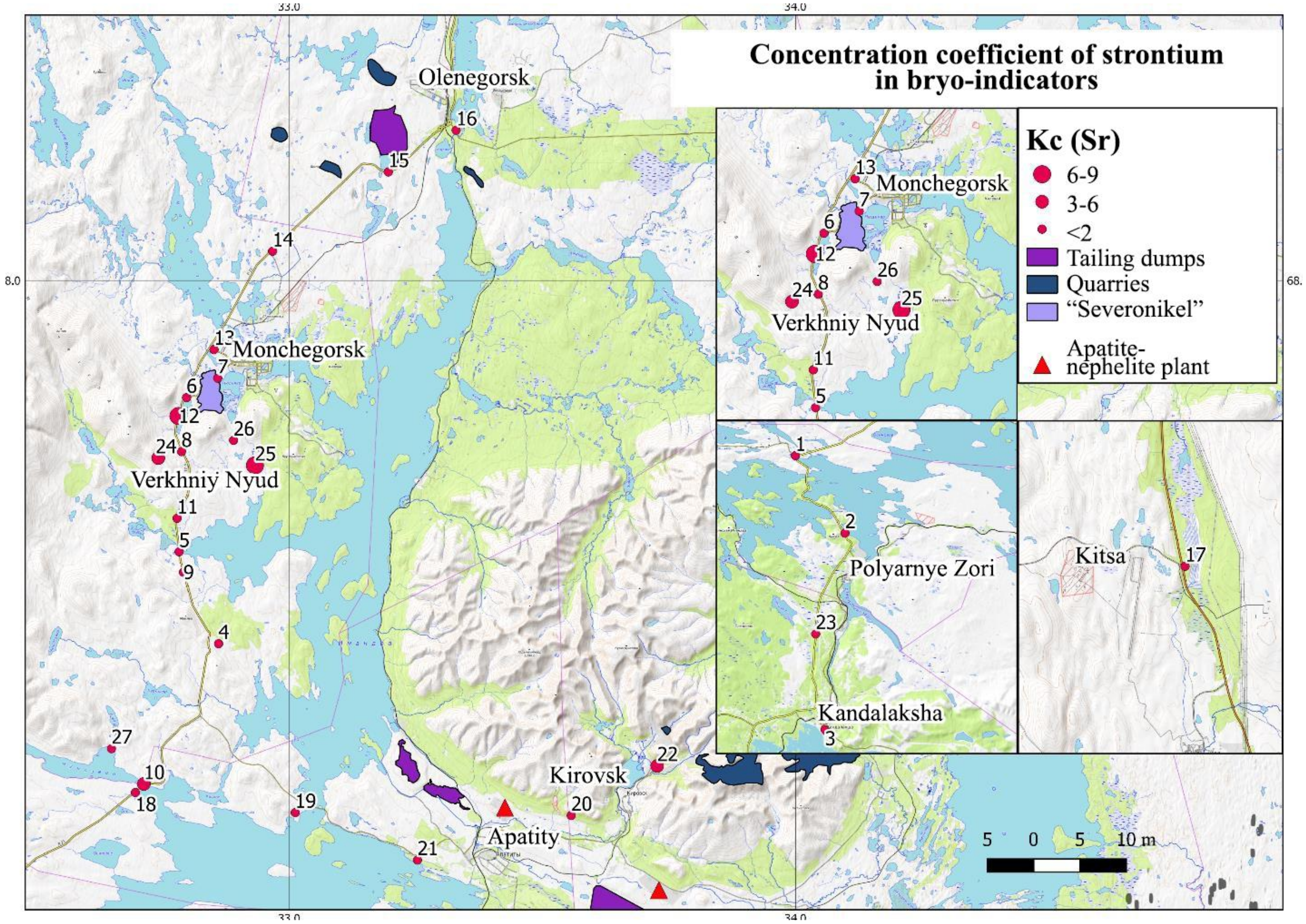

Fig. 10. Concentration coefficient of strontium in bryo-indicators.

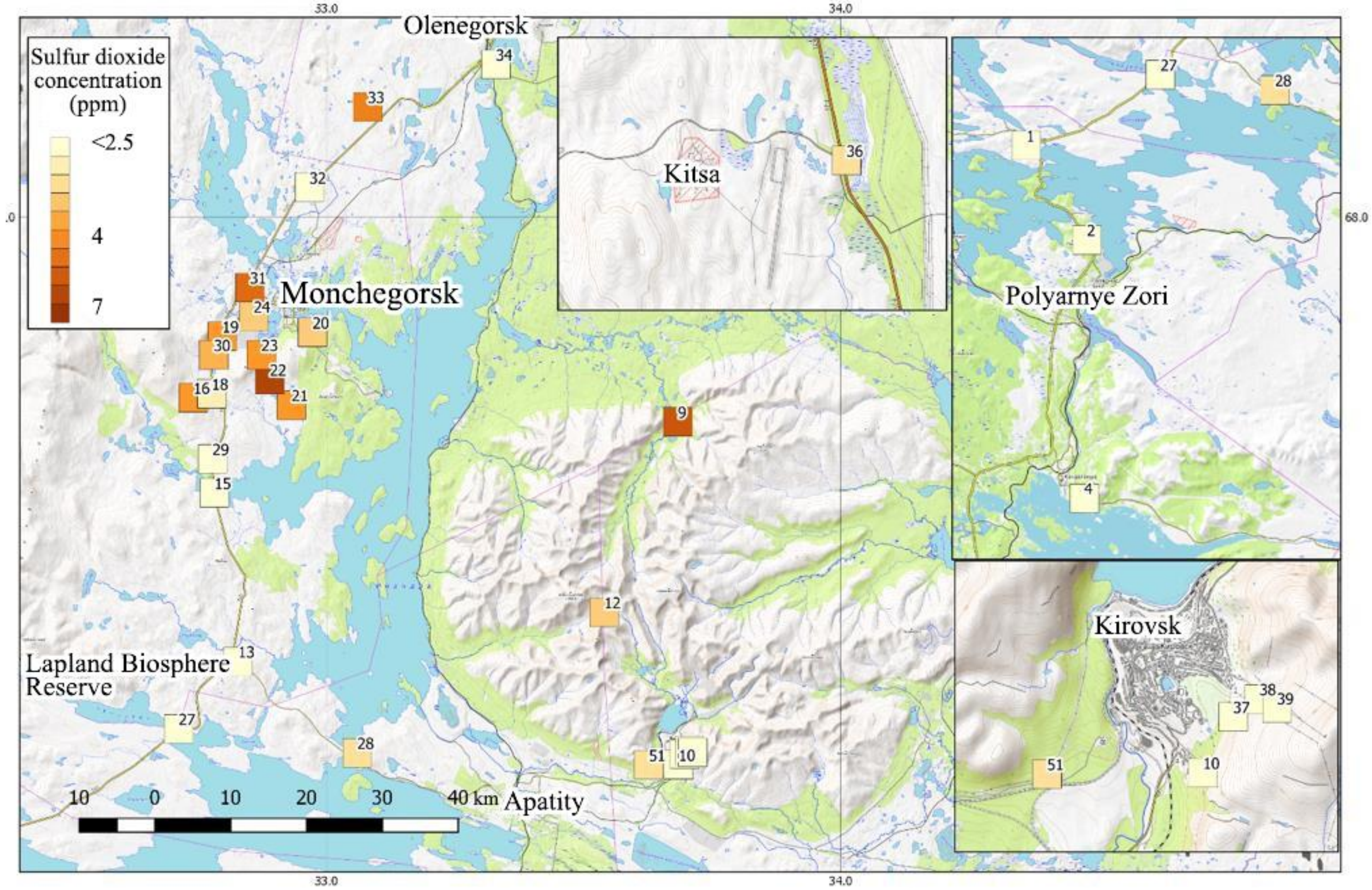

Fig. 11. Locations of the upper soil horizon sampling, carried out to assess the sulfur concentration and values of sulfur index in the field (ppm).

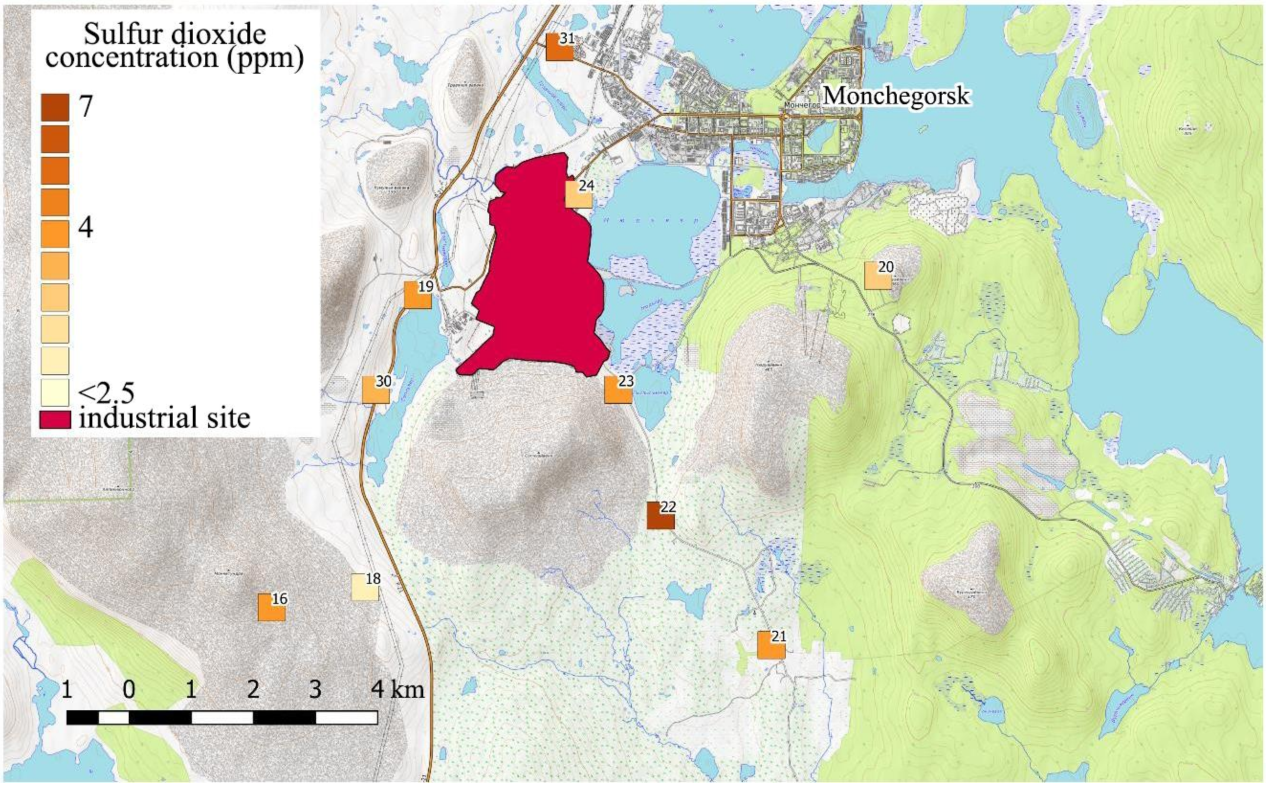

Fig. 12. Locations of the upper soil horizon sampling, carried out to assess the sulfur concentration and values of sulfur index in the field (ppm).

indicators was 6.6 for copper and 12.3 for nickel; it was not higher than 3 for strontium. To the south of the pollution source, at the points No. 3 and No. 21, located in the Lapland Nature Reserve, the copper values were 6 and 25 times higher than the normal ones, and nickel was 12 and 72 higher. It can be explained by the fact that point No. 3 was behind the orographic barrier. The strontium coefficient was not higher than 3. The excess of Kc in the bioindicators in the Lapland Nature Reserve, at the point No. 7, was 7 times for copper and 13 times for nickel. For the rest of the points the following Kc values were noted: copper – from 2.2-3.5, nickel – 3.6-6.5, strontium – 2.4-3.7.

The samples from a 40 km influence zone around the "Severonikel" rarely had any excess of heavy metals, but they had a high Kc of strontium, which made it possible to mark the Khibiny Mountains and Kirovsk and Apatity towns as the second type of influence zones. They were severely dusted due to the blasting operations in the mines and tailing dumps of the "Apatit" company.

The dusty particles contained high concentrations of strontium in lichen-indicators, which were registered in the samples (Kc up to 20). Outside the 40 km zone the bryo-indicators did not show high values of the concentration coefficient for the elements (Kc from 1 to 5.5), however the point No. 22 was noticeably affected by the "Severonikel". Kc for copper was 30.6, and 80 for nickel. There the content of strontium was increased (Kirovsk town), and Kc was 5.5.

Industrial air emissions negatively affect the health of the local population. In the studied area the main mortality cause is diseases of circulatory system (Dushkova, Yevseev, 2010). Moreover, the indices for the respiratory and Kashin-Beck diseases in the area are almost 4 times higher than the average Russian; the neoplasms, including the malignant ones, are also higher than the average for Russia. The main reason for their occurrence is pollution with heavy metals and strontium (Dushkova, Yevseev, 2011).

Conclusion

For this work the complex ecological-geographical and ecological-geochemical studies were carried out in the central part of the Kola Peninsula.

During the long period (since 1930) of the effect that mining and metal industries were causing on the components of the natural environment in the central part of the Kola Peninsula, the Central Kola impact area has formed. It can be divided into two types of zones with increased impact.

The first one was formed by the "Severonikel" factory. For many years there was a severe ecological condition around its facilities, caused by the intense emissions of the aero-industrial pollutants, such as heavy metals and sulfur compounds.

According to the data of the bryo-indication studies, the boundaries of the strong impact of the factory are located 15 km to the north (the background copper concentrations exceed the normal ones 10 times, the nickel excess is 36 times, the lead is 5 times), and 10 km to the south (copper excess is 15, nickel is 19). According to lichen-indicative studies, the area of increased input of industrial pollutants ends 30 km to the north from the plant (the copper excess is 6 times, nickel is 12, lead is 8) and 50 km to the south (copper is 5 times, nickel is 12).

The correlation method (calculation of the Cu/Ni ratio) was applied for the moss samples and showed that almost all the plots had their values lower than 1, which allowed us to conclude that during the lichen- and bryo-indication studies the nickel compounds predominated in the "Severonikel" emissions. It also confirmed that all emissions had the same source.

The studied moss, lichen and soil samples allowed us to conclude that the area of environmental pollution caused by the "Severonikel" has decreased. The initial stage of vegetation restoration in the industrial wasteland became noticeable.

The second type, formed by the mining and processing enterprises of "Apatit", is characterized by the mechanical disturbances of soil cover and ground caused by quarries, waste rock dumps, etc. are common. The pollution of its natural environment is due to the larger dust particles instead of the dispersed microparticles which are common for the areas with the mining and metal enterprises. The large amount of dusty particles on the soil cover and vegetation are ejected into the environment by the apatite-nephelite factories "Apatit" and tailing dumps. The background excess of strontium in the moss and lichen samples was more than 20 times in the Khibiny Mountains.

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