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

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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.

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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

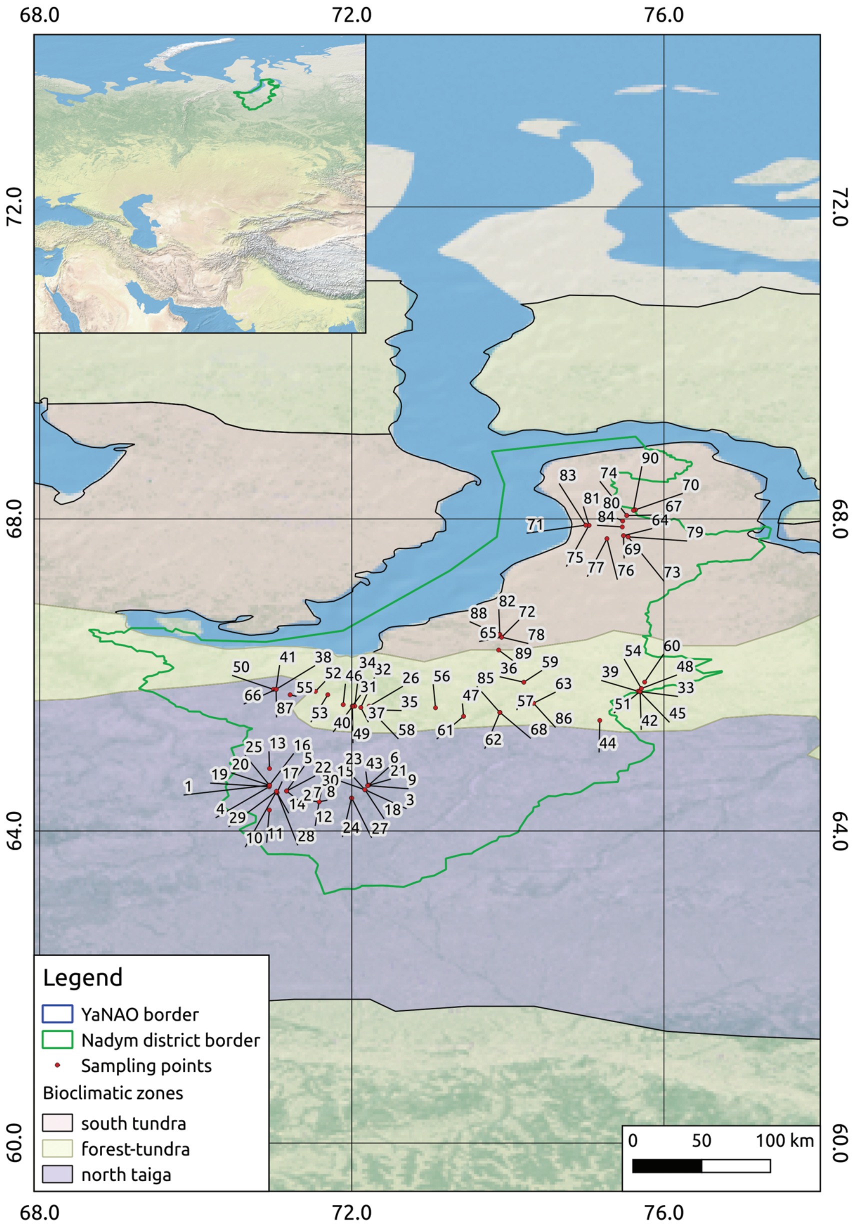

Fig. 1. Sampling sites at the Nadymski region area, YNAO

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 Kα – 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 ($K_{б2}$) 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.

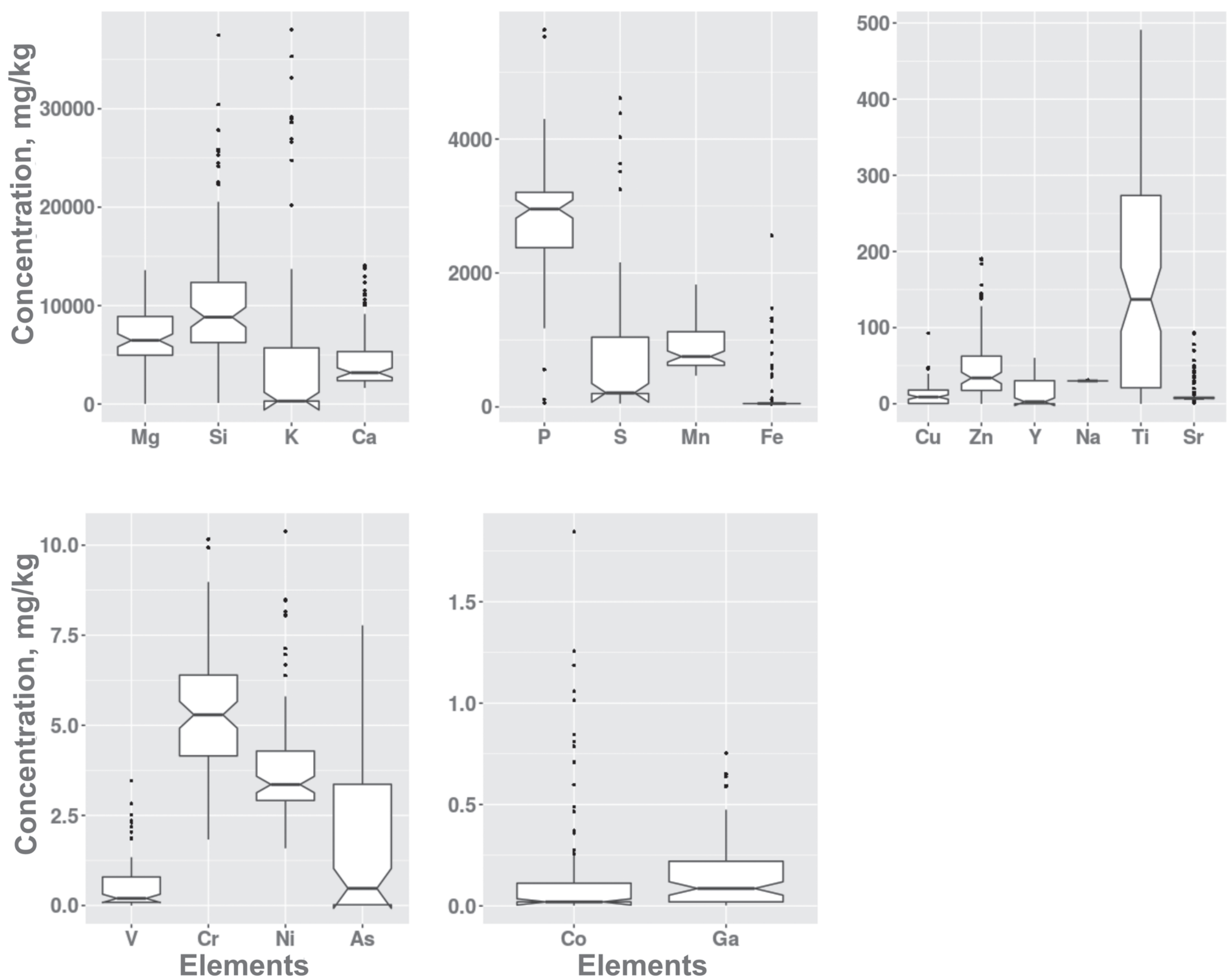

Fig. 2. Values of obtained elements concentrations. The line indicates the median, the lower and upper boundaries of block are the lower and upper quartiles, the notches show a confidence interval relative to the median, the error bars are 1.5 interquartile values (~3σ), the points are outliers (everything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

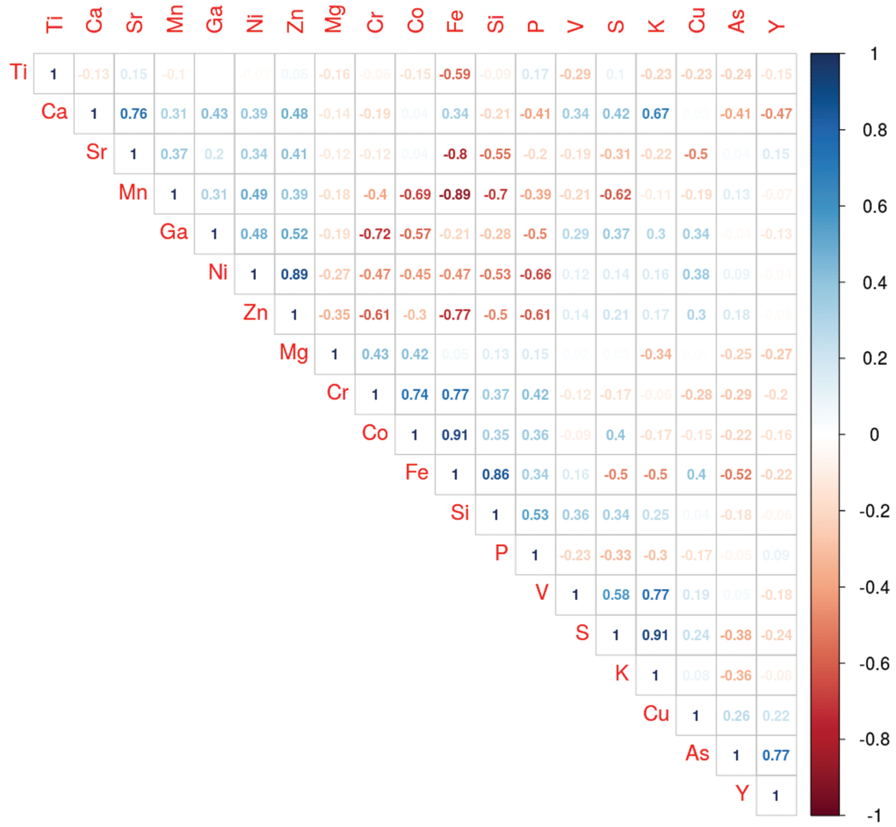

Fig. 3. *Correlation matrix among the elements concentrations in plants (according to the Spearman's test)*[1]

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

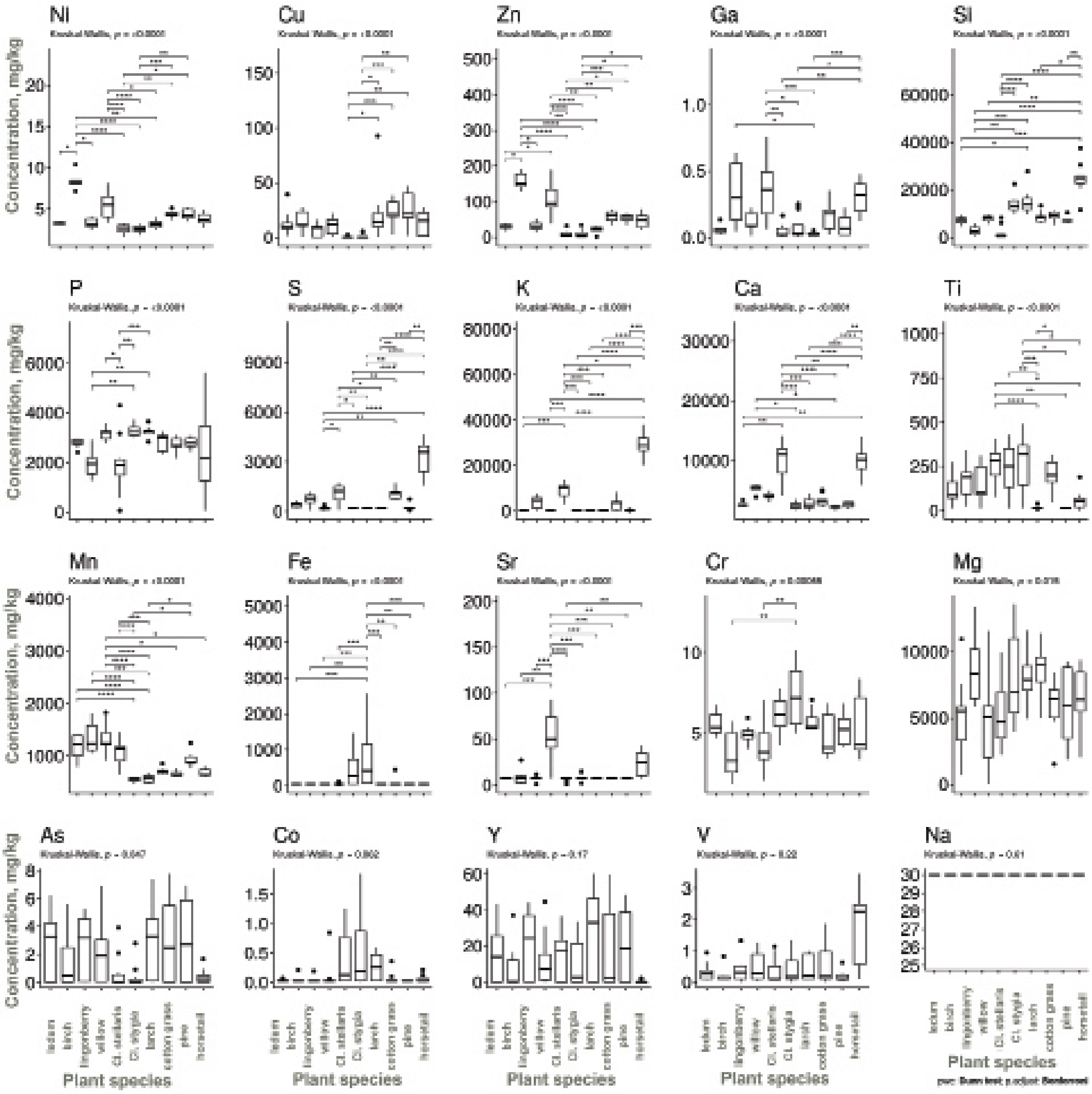

Fig. 4. Accumulation of elements by various plant species. Plant species with statistically significantly different concentrations are marked with brackets, the significance of differences is marked with asterisks (*– a weak significant difference, ***** – a strong difference)

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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

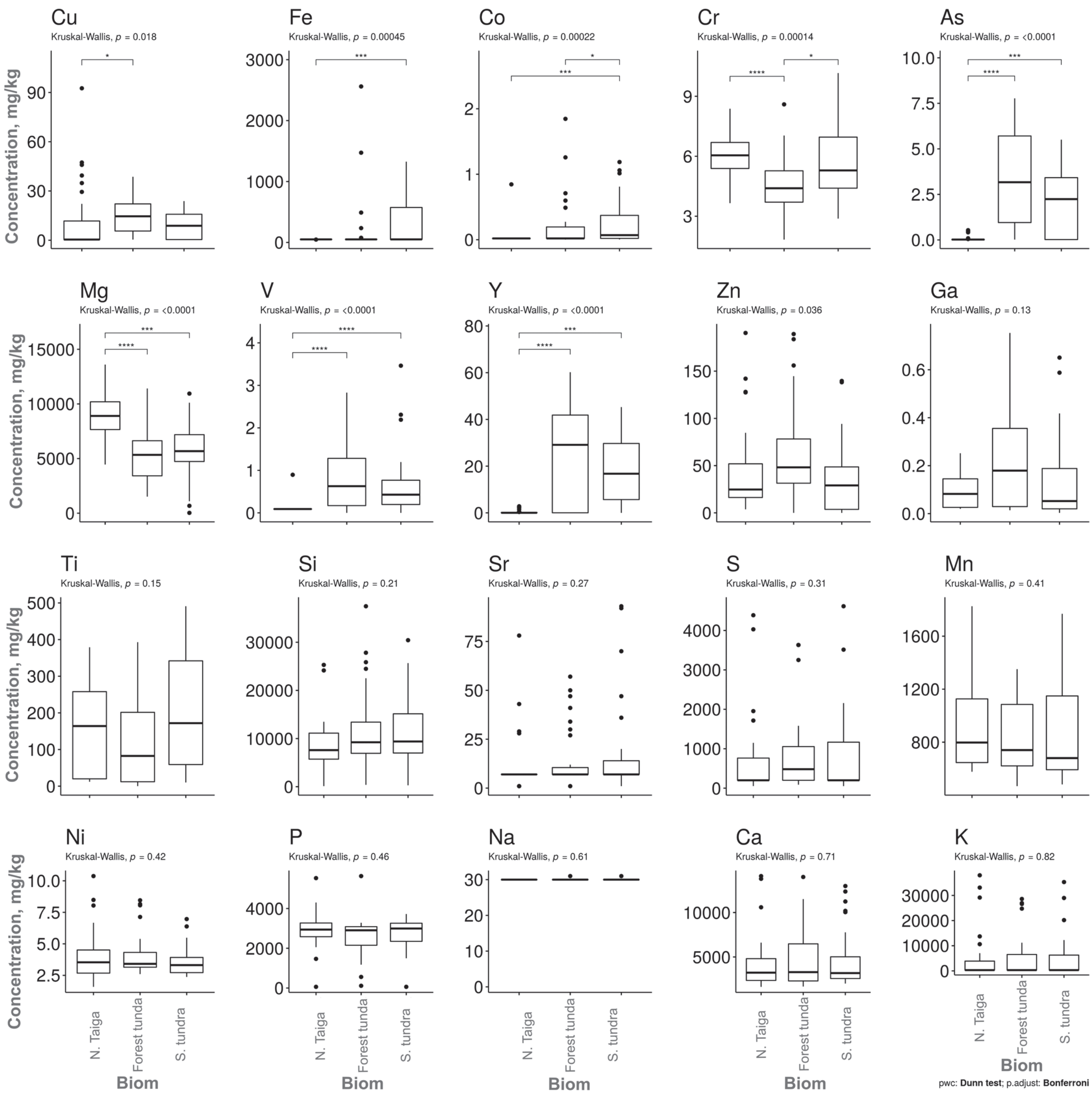

Fig. 5. The content of elements in plants at different bioclimatic subzones of the Nadymsky region, YNAO. Plant species with statistically significantly different concentrations are marked with brackets, the significance of differences is marked with asterisks (* — a weak significant difference, *****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

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 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.

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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].

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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%.

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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

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

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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