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Ecophysiological features of *Larix sibirica* in urban ecosystems of the Kola north in the railway influence zone

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Abstract

For the first time, a study of the ecophysiological features of the introduced *Larix sibirica* (middle-aged plantations old 40-50 years) was carried out at a tree nursery and railway stations in four cities in the Kola Subarctic. Content of photosynthetic pigments (per fresh weight) ranged 1185 – 1894 $\mu g \cdot g^{-1}$ (chlorophyll *a*), 377 – 666 $\mu g \cdot g^{-1}$ (chlorophyll *b*), and 256 – 387 $\mu g \cdot g^{-1}$ (carotenoids). Exception was found for the specimens from Murmansk (significantly higher) and Olenegorsk (significantly lower values). High content of Fe was found in needles (1865 – 4278 $mg \cdot kg^{-1}$), however, it did not lead to any damage or abnormalities in the development of *Larix sibirica*. A close positive correlation was shown between the Fe and Mn contents ($r = 0.91$). Ni and Cu content in needles increased in all cities from 3 to 8 times in comparison with the background, Pb content increased only in the cities of Apatity and Olenegorsk (2–4 times). The amount of Cd and Zn was found within the optimal range. This study revealed the negative effects of the main pollutants (Ni, Cu, and Pb from the mining industry) on chlorophyll *a* ($r = -0.81$) and carotenoids ($r = -0.70$).

Key words: *Larix sibirica*, heavy metals, photosynthetic pigments, railway transport

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Introduction

The most important modern globally environmental problem is the pollution of the environment with heavy metals. Their release into the atmosphere has a negative effect on soil properties, plant growth and development and represents a threat to human health. Woody plants can provide a natural universal sink capable of protecting the environment from pollution effects by accumulating and inactivating many toxic components of manmade emissions (Beckett et al. 2000, Lettens et al. 2011). The chemical composition of plants reflects the elemental composition of the soil, however, selectivity in the elements uptake reflects species-specific physiological and biochemical characteristics (Migeon et al. 2009, Wang and Jia 2010, Kopylova and Yakimova 2011).

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The mechanisms of plant resistance to an excess of heavy metals can manifest in different ways (Poonkothai and Vijayavathi 2012, Emamverdian et al. 2015). Some species can accumulate large amounts of heavy metals without any significant change or signs of damage (Viehweger 2014). Other species have several mechanisms reducing their intake by maximizing their barrier functions: (1) synthesis of stress proteins, (2) formation of complexes with chelators, (3) synthesis of metallothioneins and phyto-chelatins, (4) immobilization to the cell wall, (5) removal of heavy metal ions from the cell, (6) compartmentalization (Seregin and Ivanov 2001).

The vulnerability of urban ecosystems of the subarctic region of Russia (Murmansk region) is due to harsh soil and climatic conditions, and an intensively developed industrial complex including heavy metals pollution. Mining and industrial enterprises are local sources Most of the extracted raw materials and products are transported by rail. In addition to transporting chemicals, the maintenance and operation of rolling stock use hazardous materials that, if leaked, lead to environmental pollution (Borda-de-Agua et. al. 2017). Most pollutants, primarily heavy metals, come from the above-specified transport (Kazantsev 2015). At present, the question of the influence of railway transport on the content of metals in plants growing in the right-of-way remains poorly understood. The relevance of the work is determined by the study of plants used for landscaping railway stations located in the vicinity of cities to identify resistant species.

The purpose of this work was to assess the ecophysiological features of *Larix sibirica* from different locations of the Kola peninsula in order to identify the mechanisms of resistance to polyelemental pollution of the environment in the zone of influence of railway transport in the cities of the Murmansk region (Murmansk, Olenegorsk, Apatity, and Polyarnye Zori).

Material and Methods

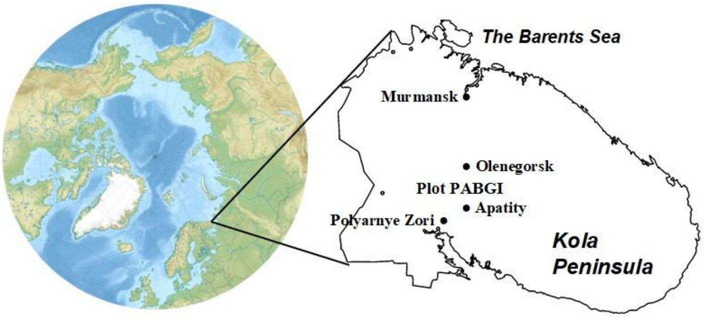
Climate characteristics of the research areas at particular locations

Location 1: Murmansk is a regional center located in the north of the Kola Peninsula (Fig. 1). The climate is continental, cold, and humid, affected by the proximity of the Barents Sea, whose influence is enhanced by the warm North Atlantic Current (Kottek et al. 2006). This factor contributes to the strong difference between the climate of Murmansk and other cities in the region. In Murmansk, winter air temperatures are higher than the average for auch latitude. The average temperature in January and February is -10° or -11°C. Severe frosts are rare, and there are occasional thaws during winter season. The onset of cold weather usually occurs about one month later than in other northern cities. The average July temperature is about +12° or +13°C. The average annual rainfall is 500 mm, most of which falls from June to October ([1]). Snow lies in average of 210 days. The minimum temperature of -39.4°C was recorded in January 1985 and Jan. 1999, and the maximum temperature of +32.9°C was recorded in July 1972. The polar night at the latitude of Murmansk lasts from December 2 to January 11 and the polar day from May 22 to July 22.

Location 2: Olenegorsk is a city 94 km south of Murmansk (Fig. 1). The climate is humid continental; the coldest month is January, when the average air temperature is -12.2°C, and the warmest month is July, with an average air temperature of +12.6°C. Average annual precipitation is 600 mm, with the maximum precipitation in July ([1]). The polar night lasts from December 8 to January 3 and the polar day from May 25 to July 17.

Location 3: Apatity is located 160 km south of Murmansk (Fig. 1). The climate is continental, cold, and humid, with the lowest average monthly temperature (January) -13.5°C (Kottek et al. 2006). The maximum average monthly temperature was recorded in July from +13° to +14°C. The average annual rainfall is 853 mm, with the greatest amount falling from September to December (about 100 mm in each of the months, [2]). Snow in Apatity lies on average 250 days and completely melts by the end of May (in the vicinity of the city, snow can lie until the beginning of June). The polar night at the latitude of Apatity lasts from December 15 to Dec. 28 and the polar day from May 20 to July 27.

Location 4: Polyarnye Zori is located 224 km south of Murmansk (Fig. 1). According to the Köppen climate classification, its climate is subarctic (Dfb index) with uniform moisture, short cool summers and very cold winters. The coldest month is January, with an average air temperature of -11.6°C, and the warmest month is July, with an average air temperature of +14.7°C. The average annual rainfall is 676 mm, with the greatest amount of precipitation from July to September. Polyarnye Zori is one of the northernmost cities on the Kola Peninsula in which there is no polar night; the polar day lasts from May 30 to July 12.



City	Location
Murmansk	68°97′N 33°07′E
Olenegorsk	68°14′N 33°31′E
Plot PABGI	67°58′N 33°30′E
Apatity	67°56′N 33°37′E
Polyarnye Zori	67°37′N 32°49′E

Fig. 1. Location of observation plots.

Characteristics of site

Railway transport in the Murmansk region has been under development since 1917, when the Murmansk railway began operating. Major railway junctions with marshalling yards are located in the cities of Murmansk and Apatity. The city of Olenegorsk is the site of a junction station with an average traffic load; the minimum level of anthropogenic impact is typical for the city of Polyarnye Zori.

Experimental species

Middle-aged (40-50 years) plantations *of Larix sibirica* grow on the territory of railway stations in four cities of the Murmansk region (Murmansk, Olenegorsk, Apatity, and Polyarnye Zori) 5–10m from the railway tracks. At the tree nursery of the Polar-Alpine Botanical Garden-Institute, located 1 km west of Apatity, *Larix sibirica* was grown from seeds obtained from the Novosibirsk Botanical Garden (the age of 45 years). *Larix sibirica* is an introduced species. It was first planted at the Kola North in the 1930s for landscaping urban areas. It requires moderate soil fertility and moisture, and is rather light-demanding. Since that, it has become widespread in polar cities.

Sampling

At the end of August 2019 at each location, needles were sampled from the middle part of the crowns of 3-4 trees from the southern and south-west sides. The samples were not washed. In alcohol extracts (96% ethanol) of fresh samples, the content of photosynthetic pigments chlorophylls *a* and *b* and carotenoids was determined spectrophotometrically at the wavelengths of λ 665, 649, and 470 nm, respectively: Calculations were performed using formulas for fresh weight (Lichtenthaler and Wellburn 1983). The preparation of plant samples for determination of total element content was performed using a DAK 100 autoclaves (Berghof, Germany) after microwave digestion in an SW4 system. Samples were analyzed using a Perkin Elmer ELAN 9000 DRC-e inductively coupled plasma mass spectrometer (ICP-MS). In laboratory conditions, the content of indicators was determined in three analytical replicates.

For a detailed analysis, seven pollutants (Pb, Zn, Cd, Ni, Cu, Fe, Mn), typical for railway transport and highly toxic to living organisms (*see* the classification below), were selected. Class I included Pb, Zn, and Cd, Class II includes Ni and Cu. In addition, biophilic elements (Fe and Mn) were analyzed. The ecological state of *Larix sibirica* was diagnosed based on the value of the Fe/Mn, Pb/Mn, and Zn/Cu ratios (Kosheleva et al. 2016).

Mathematical processing of the results was done using standard software packages for statistical calculations (Microsoft Office Excel 2016). The correlation coefficient (r) was calculated by the square method (Pearson's method) for the significance level of 0.05.

Results and Discussion

Anthropogenic pollution of the environment is a significant stress factor (Gomes et al. 2011, Biswal et al. 2011, Ashraf and Harris 2013). Plants exposed to heavy metals stress may be more sensitive to negative high light effects in photosynthetic apparatus (Takahashi and Murata 2008). An imbalance between the absorption and use of light energy in photosynthesis can lead to photoinhibition and photodestruction of the photosynthetic apparatus (Long et al. 1994, Vass and Aro 2007). The natural factors of such an effect on plants include high PAR intensity, ultraviolet radiation, temperature extremes, and water deficiency.

In the locations studied, the content of photosynthetic complex pigments in *Larix sibirica* needles varied significantly (*see* Fig. 2). The amount of chlorophyll *a* varied from 1185.16 to 1894.0 μg·g^{-1} fresh weight, with maximum values found for the Murmansk and minimum values in Olenegorsk location. In relation to the background plot (control), chlorophyll *a* was found lower in Olenegorsk. Maxima of chlorophyll *b* and carotenoids were like that of chlorophyll *a*. Chlorophyll *b* content varied from 376.96 to 666.19 μg·g^{-1}, carotenoids from 255.60 to 386.67 μg·g^{-1}. Chlorophyll *b* compared to the background was lower in all locations except for Murmansk (20% higher than the background). The carotenoid content did not differ from the background area in Apatity and Polyarnye Zori. In Murmansk it was higher, and in Olenegorsk it was much lower. The amount of carotenoids in needles was strongly correlated with chlorophyll *a* (r = 0.98) and, to a lesser extent, with chlorophyll *b* (r = 0.76).

Pigment contents in Polyarnye Zori samples (with the lowest level of anthropogenic load) showed similar values as the background, whereas in other cities it varied within wider range.

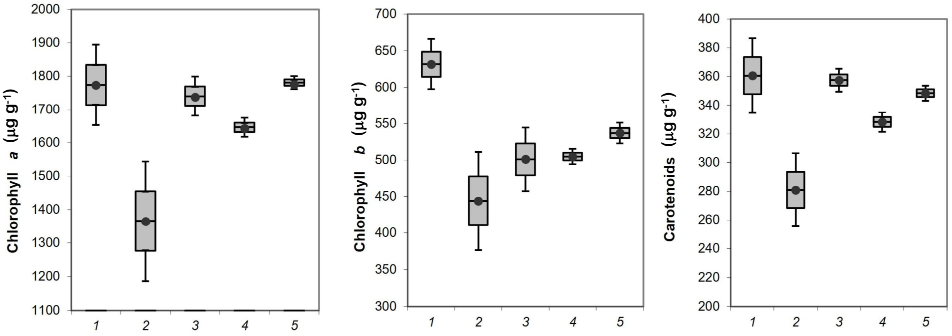


Fig. 2. Statistical parameters content (μg·g^{-1} fresh weight) of chlorophyll *a*, *b*, carotenoids in needles of *Larix sibirica*. *Note*: 1 – Murmansk, 2 – Olenegorsk, 3 – Apatity, 4 – Polyarnye Zori, 5 – Background plot.

In conditions of chronic environmental pollution, not only the content, but also the ratios of pigments change. Typically, the amount of chlorophyll *a* decreases, while the content of auxiliary pigments increases. Such changes in plants are considered to be adaptation of assimilation apparatus to the stress caused by metal ions (Saibo et al. 2009, Alieva et al. 2014, Ovechkina and Shayakhmetova 2015). The content of photosynthetic pigments and their ratio are criteria for the evaluation of functional state of woody plants under conditions of technogenic pollution and indicators of the ecological state of the environment (Tzvetkova and Hadjiivanova 2006, Afanas'eva 2018). Usually, the ratio of chlorophylls *a* and *b* and carotenoids is approximately 5: 3: 2, which is considered optimal for efficient photosynthesis (Pavlova et al. 2010).

The ratio of photosynthetic pigments in the needles of *Larix sibirica*, both in the background location and in an urbanized environment, is shifted towards a greater prevalence of chlorophyll *a* (64–67%); the proportions of chlorophyll *b* (19–23%) and carotenoids (13–14%) are reduced (Fig. 3). The higher percentage of chlorophyll *a* is caused by the long period of the polar day (about 2 months) and climatic conditions. It is not associated with pollution from rail transport.

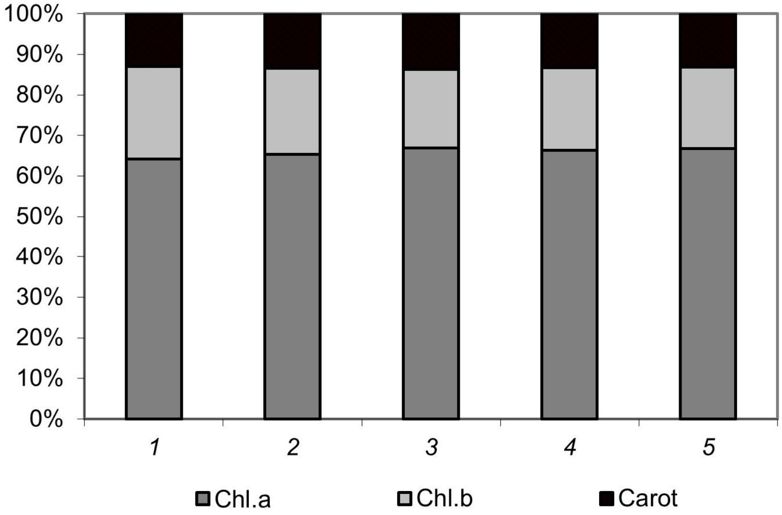


Fig. 3. The ratio of photosynthetic pigments in the needles of *Larix sibirica*. *Note*: 1 – Murmansk, 2 – Olenegorsk, 3 – Apatity, 4 – Polyarnye Zori, 5 – Background plot.

The ratios of chlorophyll *a* to *b* were found within the range of 2-3.5. The chlorophyll to carotenoids ratio ranged 4–5. Such findings are attributable to the optimal performance of the photosynthetic apparatus of plants (Dymova and Golovko 2018). In larch needles, the chlorophyll *a/b* ratio corresponded to the norm (2.81–3.47) and the chlorophyll to carotenoids ratio was overestimated (6.26–6.67), which is explained by the prevailing proportion of chlorophyll *a* in the pigment pool.

The optimal Fe content in plants is estimated as 20–200 (400) mg·kg^{-1} dry matter (Ilyin1991, Dobrovolsky 2003). An excess is observed at quantities over 550–750 mg·kg^{-1} dry matter (Kopylova 2010). Table 1 shows that in the needles of *Larix sibirica*, the Fe content in the background area corresponded to the critical value. In cities, the iron content varied from 1865.18 mg·kg^{-1} to 4278.35 mg·kg^{-1}. In Murmansk, Olenegorsk and Polyarnye Zori, this parameter changed insignificantly (exceeding the background by 2.5-3.5 times), while in Apatity maximum values exceeded the control 6 times. An interesting fact is that in Murmansk, with an increased level of load from railway transport, the Fe content is the lowest. One of the possible explanations could be that the plants in Murmansk are planted with other plants in conditions of strong thickening and shading. Symptoms of glandular toxicity are nonspecific and manifest in different ways depending on the type and stage of plant development. Often glandular toxicity is indicated by dark green leaf color or slow growth of aerial parts of plants and roots. However, in our studies, there were no visual changes in the color of the needles. Unfortunately, their size was not measured. Therefore, we can not comment the likely effect on needle size. It is shown that *Larix sibirica* has a ferral composition of ash and is a concentrator of this element (Bashkin and Kasimov 2004). It can be assumed that the iron content at the level of 4278 mg·kg^{-1} is not critical for this plant species.

City	Fe	Mn	Pb	Cu	Zn	Ni	Cd	Fe/Mn	Pb/Mn	Cu/Zn
Murmansk	1865.18	97.27	1.31	15.69	24.68	15.18	**0.068**	19.18	0.013	0.64
Olenegorsk	2635.06	118.89	**4.34**	**31.38**	**39.76**	**24.30**	0.051	22.16	**0.037**	0.79
Apatity	**4278.35**	**136.39**	2.32	25.79	37.02	10.97	0.009	**31.37**	0.017	0.70
Polyarnye Zori	2004.35	68.50	1.08	25.85	20.84	14.31	0.011	29.26	0.016	**1.24**
The tree nursery PABGI	760.00	31.00	<1.00	4.40	-	3.19	-	24.52	0.016	-

Table 1. Indicators of the ecological state of the assimilating organs of *Larix sibirica* and the content of heavy metals (mg·kg^{-1}) in needles. *Note*: - – not analyzed. The maximum values are shown in bold.

According to generalized data, the average content of manganese in plants is 15–350 mg·kg^{-1} dry matter (Pobedintseva and Dianova 1983, Ilyin 1991, Dobrovolskii 1997). The phytotoxic content of Mn for woody plants is 500 mg·kg^{-1} of dry matter (Kazantsev 2008).

In the needles of *Larix sibirica*, the amount of manganese was estimated from 68.50 (Polyarnye Zori) to 136.39 mg·kg^{-1} dry weight (Apatity), exceeding the background samples 2–4 times. Several studies have shown a definite relationship between iron and manganese. In the absence of Mn, an excess of active Fe accumulates in the plant, causing chlorosis (Moosavi and Ronaghi 2010). A high Mn content leads to a decrease in the amount of active ferrous Fe, which is mobilized in cells in the form of an oxide organophosphorus compound. In this case, chlorosis also occurs, caused by a deficiency of this element. In our studies, the correlation analysis demonstrated a direct positive relationship between the contents of these elements (Table 2). At the same time, as mentioned above, no needle chlorosis was found.

The Fe/Mn ratio indicates potential for optimum photosynthetic performance with an optimal range (1.5–2.5) for normal plant development (Kabata-Pendias 2011). Analysis of Fe/Mn revealed that the ratio in *Larix sibirica* needles is extremely high (19.18–31.37) because of excessive bioaccumulation of iron. Violation in the ratio of antagonist elements in the assimilation organs during technogenic pollution has also been noted by other authors (Siedlecka 1995).

In studies carried out in the city of Zakamensk (Republic of Buryatia, Russia), in the needles of *Larix sibirica* (native species), the maximum value of this ratio (12.3) was revealed in the residential zone of the city (Timofeev and Kosheleva 2016). The authors associate this with a sharp deficit of Mn and accumulation of Fe and suggest that this imbalance results in disturbances in the course of photosynthesis processes and deterioration of plant viability in urban areas. At the same time, in the industrial zone of the city with a greater anthropogenic load, the value of the ratio corresponded to the optimum.

Other authors noted that accumulation of pollutant elements in needles of *Larix sibirica* in the Ulan-Ude city (Republic of Buryatia) led to activation of antioxidant protection. The amount of photosynthetic pigments in needles increased 1.5–2.2 times compared with background values, mainly due to chlorophyll *b* and carotenoids. The content of Fe in needles here exceeded the background 2-7 times (Afanas'eva 2018).

	Fe	**Mn**	**Ni**	**Cu**	**Zn**	**Pb**	**Cd**
Fe	1						
Mn	**0.91**	1					
Ni	0.34	0.63	1				
Cu	0.71	0.76	0.82	1			
Zn	0.69	**0.90**	0.41	0.61	1		
Pb	0.32	0.62	0.78	0.73	**0.89**	1	
Cd	-0.53	0.02	0.55	-0.43	0.03	0.22	1

Table 2. Correlation matrix of the heavy metal content in *Larix sibirica* needles. *Note*: Correlation coefficients were shown in bold for the significance level of 0.05.

It is well known that the state of a plant and the course of biochemical processes depend on different environmental factors, both abiotic and anthropogenic ones. We assumed that the use of the Fe/Mn ratio for assessment of the ecological state of *Larix sibirica* was not entirely correct. The calculated correlation coefficients did not reveal any dependence of the content of photosynthetic pigments on the amount of Fe, Mn, and the Fe/Mn ratio (Table 3). This species, being an iron concentrator, does not show symptoms of poisoning in the form of chlorosis. Earlier, we showed that in the forecourt areas of the polar cities, middle-weakened specimens of *Larix sibirica* predominated and retained the ability to natural regeneration (Saltan and Sviatkovskaya 2021). It should be noted that the soils in the region belong to the Al-Fe humus podzolic type with naturally high iron content (Pereverzev 2004). Thus, it is possible to state only an increase in the Fe content in the needles of *Larix sibirica* in the areas near the station with respect to the background parameter.

	Ni	**Cu**	**Zn**	**Cd**	**Pb**	**Mn**	**Fe**	**Fe/Mn**	**Pb/Mn**	**Cu/Zn**
Chlorophyll *a*	-0.83	-0.72	-0.53	-0.16	-0.84	-0.37	-0.19	0.16	**-0.95**	-0.17
Chlorophyll *b*	-0.37	-0.62	-0.61	0.48	-0.70	-0.25	-0.37	-0.46	-0.74	-0.34
Carotenoids	-0.74	-0.60	-0.43	-0.13	-0.77	-0.18	-0.02	0.17	**-0.93**	-0.28

Table 3. Correlation coefficients between the heavy metal contents and pigment contents in *Larix sibirica* needles. *Note*: Correlation coefficients were shown in bold for the significance level of 0.05.

In the needles of *Larix sibirica*, the Ni content varied from 10.97 mg·kg^{-1} (Apatity) to 24.30 mg·kg^{-1} (Olenegorsk), exceeding the background value 3–8 times (Table 1). It is believed that with toxic Ni concentrations in the environment, there is a lack of Fe supply to the plant organism. However, a weak correlation was found between the contents of these elements (Table 2), caused by the relatively low amounts of Ni in the needles, and the specific features of larch (iron hyperaccumulator).

Correlation analysis of the dependence of the content of photosynthetic pigments on the amount of Ni in the needles showed high values of the negative relationship for chlorophyll *a* and carotenoids (Table 3). It should be noted that the region has a widely developed mining industry with, for example, the production of nonferrous and ferrous metallurgy and the extraction and processing of mineral fertilizers ([3]). Among all the locations, only Olenegorsk is located downwind from the Severonikel copper-nickel plant, gas and dust emissions of which affect the neighborhood. It may better explain the higher contents of heavy metals (Ni, Cu, Pb, Zn) found in the needles of *Larix sibirica* rather than the effect of railway transport. An additional negative impact is exerted by the functioning within the city limits of the OLKON mining and processing enterprise, which produces iron ore concentrate.

The Cu content in the cities was 15.69–31.38 mg·kg^{-1}, exceeding the background value 3.5 (Murmansk) – 7 (Olenegorsk) times (Table 1). Because of the effect of copper on chlorophyll biosynthesis, a correlation analysis was carried out that revealed a negative relationship between these two parameters (Table 3). There were no visual symptoms of copper poisoning.

The maximum Pb content is estimated at 0.5–1.2 mg·kg^{-1} (Kosheleva et al. 2016), but the critical value for woody plants has not been established. The amount of Pb (background) was lower than the sensitivity of the device (<1.0 mg·kg^{-1}). Comparative analysis of the lead content in *Larix sibirica* needles with the upper limit of the maximum allowable value showed that its highest accumulation is characteristic of plants growing at the railway stations of Olenegorsk and Apatity. In the rest of the locations, it is within the permissible indicators.

The Pb/Mn ratio, which characterizes the ratio of technogenic and biophilic elements, is used to judge the level of technogenic load. The optimum for uncontaminated vegetation was obtained by dividing the clarkes of these elements and is 0.006, which indicates a low proportion of Pb participation in physiological processes in plants (Dobrovolsky 2003). Analysis of the data revealed an increase of the specified value of 2 (Murmansk) – 6 (Olenegorsk) times. It has been shown that an excess of Pb in plants inhibits respiration and suppresses the photosynthetic processes by the disturbance of electron transport chain (Kabata-Pendias 2011). In our studies, this trend is confirmed at least for content of photosynthetic pigments by high significant correlation coefficients between the content of pigments and Pb (Table 3). A close negative relationship was also revealed between the Pb/Mn ratio and the content of photosynthetic pigments, especially chlorophyll *a*.

High correlation coefficients obtained between the contents of Ni, Cu, Pb and photosynthetic pigments in the needles of *Larix sibirica*, resulted from the dependence of the content of pigments on the total contents of Ni, Cu. This supported the idea of substantial influence of heavy metals on the content of chlorophyll *a* and, to a lesser extent, on chlorophyll *b* (*see* Fig. 4).

In the needles of *Larix sibirica*, the Zn content varied from 20.84 to 39.76 mg·kg^{-1} and did not exceed the optimal values (Table 1). The ratio of Zn/Cu is determined by the degree of proportionality in the provision of these biometals to the processes of fermentosynthesis. The optimum value for unpolluted vegetation is 0.27 (Elpatyevsky and Arzhanova 1990). The value of this parameter in the assimilating organs of larch in the landside territories was higher, especially in the location Polyarnye Zori, caused by the predominance of the Cu content over Zn (Table 3). The largest imbalance observed here is not related to the level of anthropogenic load from railway transport but probably has other unknown causes.

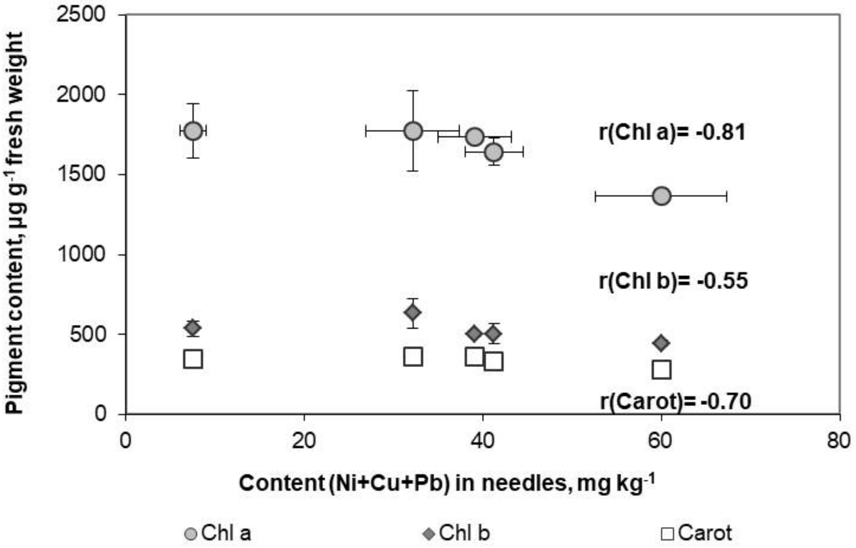


Fig. 4. The relationship between the contents of pigments and heavy metals in the needles.

The correlation coefficients calculated between the contents of Zn, chlorophylls *a* and *b*, and carotenoids had negative and lower values than for Ni, Pb, and Cu, resulting from a relatively low amount of Zn (Table 3). No antagonism was found between the intake of Zn and Cu, as well as Fe (Table 2), which is inconsistent with the previously published data on the mutual competition of these elements to inhibit their absorption by the root system. This may be due to the predominance of the foliar supply of heavy metals to plants through the roots.

The average content of Cd in plants in the range of 0.05–0.2 mg·kg^{-1} dry weight determines the area of normal content; above 5–30 mg·kg^{-1} is considered excessive or toxic (Bukharina and Dvoeglazova 2010). Close to the railway stations, the Cd content was not found over the optimum upper limit. The highest value was found in Murmansk samples (Table 1). As a result, low values of the correlation coefficients were obtained between the contents of chlorophyll *a*, carotenoids, and Cd; for chlorophyll *b*, a positive but unreliable value was found (Table 3).

Conclusion

The performed studies showed that the content of photosynthetic pigments in *Larix sibirica* needles is comparable to the background analogue, apart from Murmansk (where it is higher) and Olenegorsk (where it is significantly reduced). A change in the ratio of photosynthetic pigments in needles towards an increase in chlorophyll *a* (64–67%) and a decrease in the proportion of chlorophyll *b* (19–23%) and carotenoids (13–14%) was revealed, likely caused by climatic factors of the polar region.

High content of Fe in needles was found, significantly exceeding the background value (760 mg·kg^{-1}). The content of Mn was 2–4 times higher than the background value but within the limits of permissible values. A close direct correlation was noted between the contents of Fe and Mn (r = 0.91). The Fe/Mn ratio (used to diagnose the ecological state in *Larix sibirica* under the conditions of the Kola Polar region) was 20-30 times higher than the optimal value. The calculated correlation coefficients did not reveal the dependence of the content of photosynthetic pigments on the amount of Fe, Mn, or the Fe / Mn ratio. There were no visual deviations in size, or color of needles. *Larix sibirica* seedlings were found on the railway itself.

The degree of technogenic disturbance in the microelement composition of *Larix sibirica* needles, caused by environmental pollution by industrial enterprises, has been established. The content of Ni and Cu in needles in comparison with the background increased in all cities from 3 to 8 times and the content of Pb increased in the cities of Apatity and Olenegorsk (2-4 times); the contents of Cd and Zn were within the optimal range. An ecological and geochemical assessment of the state of *Larix sibirica* in the zone of influence of railway transport with respect to the Pb/Mn ratio showed that plants undergo technogenic pressure, especially in Olenegorsk. The value of the Cu/Zn ratio revealed a certain imbalance in the provision of enzyme synthesis caused by increased Cu content in the plant organism. The correlation analysis of the influence of heavy metals on photosynthetic pigments content revealed relatively high negative correlation coefficients between Ni, Pb, and Cu and chlorophyll *a* and, to a lesser extent, carotenoids.

Green plantations from *Larix sibirica* in the rail stations of cities are optimal for creating an ecological framework for protecting human health from the consequences of pollution caused by rail transport.

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