Heavy metals accumulation in edible forest resources in the inner-city territories

Elizaveta Pokhodnya[1*]

[1]St. Petersburg State University, Faculty of Biology, Department of Applied Ecology, Universitetskaya Emb. 7-9, St Petersburg, 199034, Russia)

Abstract. Monitoring and assessment of the potential contaminants transfer into food chains is an important component of the control of the ecotoxicological state of living systems, which reflects the ecotoxicological situation of particular areas. Consumption of wild mushrooms and berries by citizens in the inner-city and adjacent to the city territories is fraught with negative consequences for health, due to the heightened susceptibility of components of these ecosystems to anthropogenic impact, which is expressed, among other factors, in the pollutants accumulation in natural environments and the production of living communities. In the ecological realities of the XXI century, monitoring of this parameter is an important unit of the assessment and further control of toxicological safety of natural ecosystems and human. The study was devoted to the assessment of accumulation of highly toxic pollutants – heavy metals in non-timber cohort of primary production of forest communities, consumed as food by fauna of the studied area and the citizens of the adjacent areas, as well as comparison of concentrations of a number of pollutants with normatively established for safe for health food consumption levels.

1 Introduction

Among the primary production of forest ecosystems, edible forest resources take a special place as components in food chains. Moreover, the foraging of wild edible mushrooms and berries for human consumption is developed in forests and forest parks within transport accessibility from residential areas [1]. In both scenarios, the process of edible forest resources consumption lead to the introduction of accumulated substances, including such toxic as heavy metals, an important factor in the issue of which input into the natural habitats of forests is anthropogenic activity, the consequence of which is the environment pollution, including pollution of soils, one of the key components of the soil-plant complex in any terrestrial ecosystem capable to accumulate pollutants with their further migration into the conductive tissues of other components of ecosystems – plants, as well as fungi, into living organisms with an increase in their concentrations at higher trophic levels [2]. In this context, special attention, along with the study of pollutant levels directly in fruits consumed for food, should be paid to the process of pollutants migration in the structural units of plant organisms.

* Corresponding author: elizaveta902@mail.ru

Today, the foraging of edible forest resources in the form of mushrooms and berries in the territories of inner-city or suburban green areas by residents of cities, including such large agglomerations as St. Petersburg, is still popular. In addition, a trend called city gardening has recently developed, which consists in the consumption of produce grown in inner-city, including inner-quarter, territories [3], and, among other things, carries a dangerous factor of entrance of toxicants, produced and accumulated in increased quantities by the urban environment, into the organisms of consumers. Bioaccumulation of pollutants is one of the most dangerous factors, also arising from the food use of wild mushrooms and berries [4, 5]. In this regard, the issue of natural food resources ecotoxicology is of particular relevance.

In course of this study, in the summer-autumn of 2024, terfas of a number of edible fungi of three genera were sampled in the territory of the Yuntolovsky Sanctuary and the adjacent Yuntolovsky Park, located in close proximity to residential areas of Primorsky District of St. Petersburg and popular and actively attended for the purpose of gathering wild mushrooms and berries for further consumption: *Leccinum*, *Suillus*, and *Russula*, which spawns were found in the coastal-aquatic areas of the study territory, as well as vegetative (leaves and stems) and generative (fruits) organs of a number of plants actively fruiting in these conditions, represented mainly by tree and subshrub layers, belonging to four genera: rowan (*Sorbus*), *Viburnum*, *Vaccinium*, *Rubus*, growing in sites with varying degree of bogginess and in river valleys and near the shore of Lake Lakhtinsky Raliv, and analysed for their accumulation of heavy metals. In addition, for a comparative assessment of heavy metals accumulation by the terfas of mushrooms and the degree of their toxicological hazard when consumed as food, their sampling was carried out in a contrasting territory to the Yuntolovsky Sanctuary - on the lawns of residential areas of St. Petersburg, where, as well as in forest areas, they are collected by the local residents for the purpose of food use.

The efficiency of forest resources food use in the boreal zone of Russia is growing as a reflection of the consumer market of wild-growing edible forest products development [6].

Fruits of plants of different layers, as well as fungi terfas in the system ‘soil-plant’ and ‘soil-fungus’ provide a transfer of pollutants to higher trophic levels, which may have unfavourable consequences [7]. Control of chemical contamination of food products of wild berries and fungi is important both for prevention of pollutants intake into living organisms increase and as an indicator of the territory susceptibility to anthropogenic pollution.

In the conditions of permanent high load on the components of natural landscapes, produced by external impact, mainly by anthropogenic pollution, which implies the entry of a numerous chemical pollutants, including such highly toxic ones as heavy metals, into the environment, among which forest ecosystems [8, 9], it is important to assess the safety of edible forest resources, based on both quantitative and qualitative indicators.

For today numerous Russian and foreign studies confirm the fact of heavy metals bioaccumulation in various living objects and postulate significantly different levels of the pollutants accumulation in different plant species and other components, but most of them are still devoted to agricultural species [10, 11]. Despite the urgency of the problem of forest food resources contamination with heavy metals, currently there is no much information about contamination of various organs (vegetative and, mainly, generative - fruits) of wild plants and fungi terfas. However, it is known from available studies that, unlike plants, fungi have a significantly lower resistance to pollutants accumulation [12].

Exposure to pollutants (heavy metals) in low doses in territories characterised by different levels of susceptibility to anthropogenic (technogenic) impact of various kinds does not immediately affect the state of ecosystems, and external signs of negative impact may be noticeable only in temporal dynamics [13]. Therefore, the study of migration processes of pollutants in structural elements of ecosystems from industrial facilities in relatively unpolluted (background) and polluted areas of wild berries and fungi is of special interest.

Sorption capacity and bioaccumulation levels, as well as directly related to them barrier functions against pollutants in plants and fungi depend on a number of factors, including species, physiological state and age, soil contamination level and its physicochemical, morphological and edaphic features, other external conditions, as well as pheno-stage of vegetation period for plants [14].

The human body is also capable to accumulate pollutants, mainly from food [15]. It is known from the literature that no heavy metal toxicant is eliminated from the organism immediately after intake, even if its concentration was insignificant – even the results obtained after a single intake of pollutant indicate that up to 20% of the toxicant is retained in the body for a month [16]. Therefore, obtaining ecologically and toxicologically safe products is an important of our time.

The purpose of this work was to assess and compare the ecotoxicological state, determined by the heavy metals content, of wild berries plants and fungi consumed as food by the city residents, growing within the boundaries of the metropolis in the territories, represented by large green massifs (in this case – the inner-city protected area and its protective buffer zone) and green plantings in residential neighbourhoods, experiencing a significantly greater anthropogenic load, manifested, among other things, in the production and accumulation of pollutants.

2 Materials and methods

To assess heavy metals in forest food resources during the period of maximum productivity of the non-timber cohort of plant community products, generative (fruits) and vegetative plant organs were sampled for further comparative assessment of the intensity of pollutant accumulation in different organs of the plant, the efficiency and changes in barrier functions, and basidial pileate fungi terfas.

The following plant species served as objects of the study: guelder rose (*Viburnum opulus* L.), rowan (*Sorbus aucuparia* L.), European blueberry (*Vaccinium myrtillus* L.), European red raspberry ((*Rubus idaeus* L.), red whortleberry (*Vaccinium vitis-idaea* L.), bog cranberry (*Vaccinium oxycoccos* L.). The berries of these plants are actively consumed both by representatives of the abundant fauna of the studied area, which entails the entry of all their accumulated substances into food chains, often reaching humans, and by the and by the citizens of the neighbouring residental districts. In addition to fruits, vegetative organs, such as leaves and stems, were sampled from a number of species among those studied.

Among the representatives of mycorrhizal communities, the following species were subject to the study: orange birch bolete (*Leccinum versipelle* (Fr. & Hök) Snell), slippery jack (*Suillus luteus* (L.) Gray), rough-stemmed bolete (*Leccinum scabrum* (Bull.) Gray), emetic russula (*Russula emetica* (Schaeff.) Pers.), birch brittlegill (*Russula betularum* Hora), yellow russula (*Russula claroflava* Grove), entire russula (*Russula integra* (L.) Fr.), including both pore and agaric fungi. For comparison, fungi of the species field mushroom (*Agaricus campestris* L.) were also sampled in a small green area of the Admiralteysky district (Olympia Garden) and on lawns in residential neighbourhoods in the Petrogradsky district.

Also at all sample sites, in addition to the above-mentioned research objects, soils were sampled from the root zones of plants, as well as under mushroom spawns.

The key parameter on the basis of which the ecotoxicological assessment of the investigated material was carried out was the accumulation and content of the following heavy metals: strontium, lead, arsenic, zinc, nickel, cobalt, chrome, obtained by X-ray fluorescence spectroscopy in accordance with FR.1.31.2018.32143 using a Spectroscan Max-G spectrometer.

Concentrations of heavy metals in berries and fungi terfas were compared with the normatively permissible values established by the Technical Regulation of the Customs

Union 021/2011 “On Food Safety” which determines maximum permissible levels of the following pollutants in fruit and vegetable products out of the measured ones: lead, arsenic and chromium - in berries, lead and arsenic – in fungi (Table 1).

Table 1. Maximum permissible levels of content of some heavy metals in berries and fungi, established by TR CU 021/2011.

Products	Pb, mg/kg	As, mg/kg	Cr, mg/kg
Berries	0.4	0.2	0.5
Fungi	0.5	0.5	The value is not been established

Quantitative and qualitative assessment was carried out for all organs of the studied plants on the basis of biological accumulation coefficients calculated according to formula 1 proposed by A.I. Perelman:

$$K = l_n/n_x \quad (1),$$

where l_x is the concentration of the element x (heavy metal) in plant tissues, mg/kg, n_x is the element (heavy metal) content in soil, mg/kg.

The assessment of the biological accumulation intensity was determined according to the following gradation, in accordance with the A.I. Perelman’s method: elements, which biological accumulation coefficient values were in the range of 10-100, were referred to Group I of accumulation and the degree of vigorous accumulation, with coefficient values of 1-10 they were referred to Group II and the degree of strong accumulation, Group III and the degree of weak accumulation or medium capture corresponded to the range of values 0.1-1, Group IV and the degree of weak capture - 0.01-0.1, Group V and the degree of very weak capture - 0.001-0.01 [17].

3 Results

The study of heavy metals accumulation in edible forest plant resources showed a pronounced species specificity of plants with regard to pollutants and their uneven concentration in vegetative and generative organs of the same vegetative organism. Strontium accumulation was maximum in leaves and berries of rowan (*Sorbus aucuparia* L.) (130-150 mg/kg), its minimum was recorded in bog cranberry (*Vaccinium oxycoccos* L.) berries (7 mg/kg); lead showed approximately equal accumulation in all studied plants (0-6 mg/kg), its maximum concentration was in leaves of European blueberry (*Vaccinium myrtillus* L.) (6 mg/kg), while leaves of bog cranberry (*Vaccinium oxycoccos* L.) were the only objects among the studied that did not accumulate this pollutant. Arsenic was uniformly accumulated in all plants and their organs (2-4 mg/kg), while zinc concentrations showed a wide variety: the highest concentrations were found in berries of European blueberry (*Vaccinium myrtillus* L.) (245 mg/kg), the least – in berries of red whortleberry (*Vaccinium vitis-idaea* L.) (33 mg/kg) and bog cranberry (*Vaccinium oxycoccos* L.) (30 mg/kg). The maximum nickel concentrations were recorded in the leaves of guelder rose (*Viburnum opulus* L.) (10 mg/kg) and European blueberry (*Vaccinium myrtillus* L.) (9 mg/kg), the minimum – in the leaves of bog cranberry (*Vaccinium oxycoccos* L.) (1 mg/kg). For cobalt, the lowest accumulation was observed in all the material examined (0-2 mg/kg), while for chromium, the maximum accumulation was clearly expressed in berries of guelder rose (*Viburnum opulus* L.) (141 mg/kg), while in other organs of this plant and all organs of other species included in the research its concentrations were at the level of 26-29 mg/kg.

Calculation of biological accumulation coefficients for different organs of the studied plants allowed to reveal that the most intensively accumulated pollutants were zinc, chromium and strontium (Table 2).

Table 2. The biological accumulation groups of heavy metals in vegetative and generative organs of plants.

Species	Organs	Sr	Pb	As	Zn	Ni	Co	Cr
Guelder rose (*Viburnum opulus* L.)	Berries	III	III	III	III	III	IV	II
	Leaves	III	III	III	III	III	IV	III
Rowan (*Sorbus aucuparia* L.)	Berries	III	IV	III	III	III	IV	III
	Leaves	II	IV	III	III	III	IV	III
European red raspberry (*Rubus idaeus* L.)	Berries	III	IV	III	III	III	V	III
European blueberry (*Vaccinium myrtillus* L.)	Berries	III	IV	III	III	IV	III	III
	Leaves	III	IV	III	III	III	IV	III
	Steams	III	IV	III	II	III	III	III
Red whortleberry (*Vaccinium vitis-idaea* L.)	Berries	III	IV	III	III	III	III	III
	Leaves	III	IV	IV	III	III	V	III
Bog cranberry (*Vaccinium oxycoccos* L.)	Berries	III	III	III	II	II	II	III
	Leaves	II	V	III	II	II	II	II

The pollutant most intensively accumulated in fungi was zinc, its concentrations reached 268 mg/kg in terfas of field mushroom (*Agaricus campestris* L.) sampled in Petrogradsky district and 259 mg/kg in terfas of orange birch bolete (*Leccinum versipelle* (Fr. & Hök) Snell) from the Yuntolovsky Sanctuary. Arsenic and cobalt accumulated with equal intensity in all the fungi accepted for the study. The maximum of strontium content was recorded in birch brittlegill (*Russula betularum* Hora) – 70.5 mg/kg, the minimum was its concentration in orange birch bolete (*Leccinum versipelle* (Fr. & Hök) Snell) – 35.3 mg/kg. Nickel content varied in a narrow range: from 2 mg/kg in slippery jack (*Suillus luteus* (L.) Gray) to 7.5 mg/kg in birch brittlegill (*Russula betularum* Hora). The chromium content reached a maximum of 37 mg/kg in birch brittlegill (*Russula betularum* Hora), its minimum (25 mg/kg) was recorded in slippery jack (*Suillus luteus* (L.) Gray) (Table 3).

Table 3. Some heavy metals concentrations in wild mushrooms.

Growing area	Species	Sr, mg/kg	Pb, mg/kg	As, mg/kg	Zn, mg/kg	Ni, mg/kg	Co, mg/kg	Cr, mg/kg
Yuntolovsky Sanctuary	Birch bolete (*Leccinum versipelle* (Fr. & Hök) Snell)	35.33	3.33	4.00	233.00	3.00	1.67	29.33
	Rough-stemmed bolete (*Leccinum scabrum* (Bull.) Gray)	52.00	0.00	4.50	175.00	2.50	2.00	30.50
	Emetic russula (*Russula emetica* (Schaeff.) Pers.)	56.00	0.00	4.00	263.00	6.00	1.00	32.00
	Entire russula (*Russula integra* (Singer) Romagn. ex Bon)	44.00	2.00	4.00	118.00	4.00	3.00	28.00
	Birch brittlegill (*Russula betularum* Hora)	70.50	2.00	3.50	108.50	7.50	3.00	37.00
	Yellow russula (*Russula claroflava* Grove)	41.00	4.00	4.00	234.00	4.00	3.00	26.00

	Slippery jack (*Suillus luteus* (L.) Gray)	38.00	0.00	5.00	207.00	2.00	1.00	25.00
Admiralteysky district	Field mushroom (*Agaricus campestris* L.)	46.00	9.00	6.00	133.00	5.00	1.00	31.00
Petrogradsky district	Field mushroom (*Agaricus campestris* L.)	50.00	7.00	5.00	227.50	2.50	1.50	28.00

4 Discussion

It was shown that group III of biological accumulation prevails for most pollutants, which corresponds to the degree of "weak accumulation or medium capture". The most significant disturbances of barrier functions were recorded in bog cranberry (*Vaccinium oxycoccos* L.) both in vegetative and generative organs, while leaves of red whortleberry (*Vaccinium vitis-idaea* L.) showed the greatest resistance to pollutant accumulation.

No unambiguous pattern and gradient of the intensity of pollutant accumulation in different organs was observed, but in most plants berries accumulated heavy metals to a greater extent compared to leaves. European blueberry (*Vaccinium myrtillus* L.) steams accumulated pollutants to a greater extent in comparison with other plant organs of this species.

Measurement of heavy metals concentrations in fungi allowed to reveal that their accumulation is more intensive in agaric fungi than in pore ones, which is typical and has been repeatedly described in literature [18].

Comparison of actual concentrations of heavy metals in berries and fungi with normatively established permissible values for safe food consumption of products containing these substances allowed to record exceedances of maximum permissible levels in all berries with regard to all considered toxicants, and almost all fungi. Only in a few species of fungi growing in the territory of the Yuntolovsky Sanctuary, the permissible level of lead content was not exceeded (Table 4).

Table 4. Exceedances of normatively permissible levels of some heavy metals in wild mushrooms and berries.

<table>
<tr><td colspan="5">Berries</td></tr>
<tr><td colspan="2">Species</td><td>Pb</td><td>As</td><td>Cr</td></tr>
<tr><td colspan="2">Guelder rose (Viburnum opulus L.)</td><td>10.00</td><td>20.00</td><td>282.00</td></tr>
<tr><td colspan="2">Rowan (Sorbus aucuparia L.)</td><td>11.25</td><td>15.00</td><td>58.00</td></tr>
<tr><td colspan="2">European red raspberry (Rubus idaeus L.)</td><td>10.00</td><td>15.00</td><td>56.00</td></tr>
<tr><td colspan="2">European blueberry (Vaccinium myrtillus L.)</td><td>3.75</td><td>20.00</td><td>59.00</td></tr>
<tr><td colspan="2">Red whortleberry (Vaccinium vitis-idaea L.)</td><td>8.75</td><td>20.00</td><td>55.00</td></tr>
<tr><td colspan="2">Bog cranberry (Vaccinium oxycoccos L.)</td><td>12.50</td><td>20.00</td><td>52.00</td></tr>
<tr><td colspan="5">Mushrooms</td></tr>
<tr><td>Growing area</td><td>Species</td><td>Pb</td><td>As</td><td>Cr</td></tr>
<tr><td rowspan="4">Yuntolovsky Sanctuary</td><td>Birch bolete (Leccinum versipelle (Fr. & Hök) Snell)</td><td>6.67</td><td>8.00</td><td rowspan="4">Normative values are not established</td></tr>
<tr><td>Rough-stemmed bolete (Leccinum scabrum (Bull.) Gray)</td><td>0.00</td><td>9.00</td></tr>
<tr><td>Emetic russula (Russula emetica (Schaeff.) Pers.)</td><td>0.00</td><td>8.00</td></tr>
<tr><td>Entire russula (Russula integra (Singer) Romagn. ex Bon)</td><td>4.00</td><td>8.00</td></tr>
</table>

	Birch brittlegill (*Russula betularum* Hora)	4.00	7.00	
	Yellow russula (*Russula claroflava* Grove)	8.00	8.00	
	Slippery jack (*Suillus luteus* (L.) Gray)	0.00	10.00	
Admiralteysky district	Field mushroom (*Agaricus campestris* L.)	18.00	12.00	
Petrogradsky district	Field mushroom (*Agaricus campestris* L.)	14.00	10.00	

Exceedances of permissible levels were recorded both for fungi growing within the boundaries of the protected area and in residential areas of city districts close to motorways, which indicates unsafe of their consumption in both cases.

5 Conclusion

The assessment of potential transfer of toxicants into food chains by the consumption of wild mushrooms and berries growing in the territory of the Yuntolovsky Sanctuary allowed to determine the threatened state: edible forest resources are significantly contaminated with heavy metals, especially zinc and chromium.

The accumulation of pollutants in edible forest resources consumed for food, including by the urban population, poses a threat of their transfer into food chains with increased concentrations at higher trophic levels, which may entail adverse consequences for the health for categories of people, for whom the foraging of wild mushrooms and berries with further food consumption is popular.

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