Int. J. Environ. Res., 2(2): 111-124, Spring 2008
ISSN: 1735-6865

The status of whitefish population from Chuna Lake in the Lapland Biosphere Reserve Russia

Kashulin, N. A.,* Terentiev, P. M. and Koroleva, I. M.

Institute of the North Industrial Ecology Problems, Kola Science Centre, Russian Academy of Sciences 14a Fersman St., Apatity 184200, Russia

Received 12 Aug 2007; Revised 20 Dec. 2007; Accepted 15 Jan. 2007

ABSTRACT: The current state of whitefish population and their organisms have been investigated in subarctic Lake Chuna exposed to long-term air pollution from copper-nickel industry. Both annual and long-term heavy metals and acid oxides loads on the lake have been determined. A qualitative assessment has been made for water and bottom sediments. The investigation results have been compared with those of the archived data (the 1950s -1960s studies) to reveal a number of changes. The lifetime of whitefish has shortened, with early maturity and spawning. Pathological changes of whitefish inner organs occur more frequently. Assessment was made for the Cu and Ni concentrations in whitefish organs and tissues, the seasonal dynamics and peculiarities of metal accumulation in two different species. The revealed changes of the biological constituent of the lake ecosystem alongside with hydro-chemical indices of air-borne load is suggestive of adverse impact of long-term air-borne pollution on the Lake Chuna ecosystem.

Key words: Whitefish, Population structure, Heavy metals, Air pollution, Lake, Subarctic, Chuna

INTRODUCTION

Protected areas occupy about 10% of the Murmansk region area (Veshnjakov, *et al.*, 1999). The very existence of protected areas mitigates anthropogenic load on aquatic and terrestrial ecosystems. At the same time, industrial operations concentrated within a relatively small area in the Kola region produce adverse impact on the ecosystems: for instance, the biological reserves of the inland water-bodies are reduced, particularly, those of ichthyofauna (Kashulin, *et al.,* 1999; Moiseenko, 1997; Moiseenko and Jakovlev, 1990; Moiseenko, *et al.,* 2002). Some areas adjacent to the metallurgical and mining enterprises of the Kola Peninsula are the most polluted ones in the Arctic (AMAP, 1998, 2003, 2004, 2005, 2006).

Special consideration should be given to toxic effects produced by heavy metals on biological systems (AMAP, 2000). Large copper-nickel plants operating on the territory of the Murmansk region emit acid-forming substances and heavy metals into the atmosphere. The main pollutants are copper, nickel and sulfur dioxide. In 2000-2002, the annual SO_2 emission accounted for 167-196.5 thousand tons, those of copper and nickel accounted for 865 – 1079 and 1145 – 1570.5 tons per year, respectively (Mokrotovarova, 2003).

The whitefish (*Coregonus lavaretus L.*) is the most widespread species of the fresh water ichthyofauna of the Kola Peninsula. This species is circumpolar distributed (Reshetnikov, 2003). The whitefish is sensitive to water pollution (Cooley, *et al.,* 2002; Kleverkamp,2002; Kleverkamp, *et al.*, 2000; Munkittrick and Dixon, 1989). So this species can be widely used in assessment of freshwater ecosystems polluted by different pollutants, including heavy metals (Kashulin, 1995; Kashulin, *et al.,* 1999; Moiseenko, 1997; Moiseenko and Jakovlev, 1990; Ptashinsky and Kleverkamp, 2002). The purpose of the present study is to assess the whitefish population in Lake Chuna located on the territory of the Lapland biosphere reserve. A series of ichthyological studies was performed on the territory of the reserve in the early 1950s and 1960s

*Corresponding author: Email-nikolay@inep.ksc.ru

(Vladimirskaya, 1950, 1951, 1956; Reshetnikov, 1962, 1963, 1964 a, b, 1966, 1967, 1975).

MATERIALS & METHODS

The studies were performed from September 2000 till February 2001. Lake Chuna is located in the south-eastern part of the Lapland biosphere reserve (Fig.1). The catchment area of the lake is located 40 km south-west of «Severonickel» copper-nickel industrial complex (Veshnjakov, *et al.*, 1999). The lake's area is 2226 hectares, over 20 km long and ~1 km wide. The lake is located 128 m a.s.l. In its eastern part, the lake is as great as 3 km. It is a deep, poorly warmed-up lake formed in a tectonic fracture (Vladimirskaya, 1951). The lake's depth is locally rather great, reaching to 30m; it is of an elongated shape and with an underdeveloped littoral.The studies carried out in the lake have defined two major zones: a feeding area, in the eastern and widest part of the lake, and a spawning area, in the western part of the lake where the Chuna River flows into the lake (Fig.1).In order to determine the air-borne Ni/Cu industrial load on Lake Chuna, a model developed by N.E. Ratkin, INEP KSC RAS (Ratkin, 2006), was applied.

Water sampling was carried out in the lake in the surface and near-bottom (at depth > 3 m) layers by a plastic bathometer into polyethylene bottles. Chemical-and-analytical analyses were performed in laboratory. The samples were analyzed for: pH, alkalinity, sulphates, chlorides, K, Na, Ca, Mg and heavy metals content. All the analytical methods applied to determine the major hydro-chemical parameters were adjusted to the international standards (APHA, 1975; Lurje, 1984; Semenov, 1977). The tests have been conducted by a potentiometric method (pH, alkalinity) as well as by ion-chromatography (sulphates, chlorides), atomic-emission spectrometry (K, Na) and atomic absorption methods (AAS-360-Ca, Mg), (AAS Perkin-Elmer-5000 with a graphite atomizer HGA-400 – Cu and Ni), (AAS AAnalyst-800 – Co, Zn, Pb, Cr, Cd), (flame atomization method, AAS-30 Carl Zeiss Iena – Mn, Sr, Fe). The quality of the data obtained has been assessed by comparison with the standard-samples solutions within the framework of the international inter-calibration (Inter-comparison 0115, Norwegian Institute for Water research, 2001).

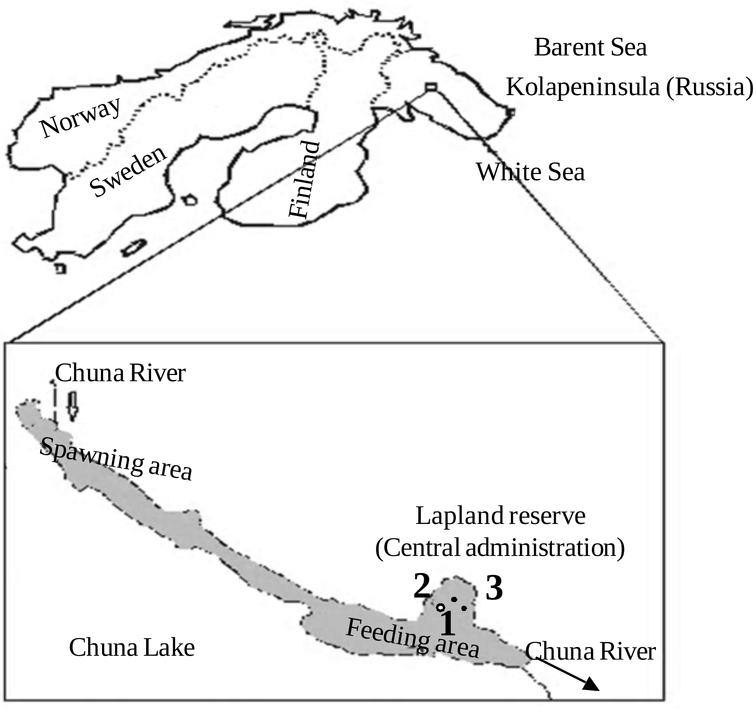


Fig.1. The study area (the sampling sites are marked by points)

Bottom sediments have been sampled by an open-gravitation sampler (Skogheim, 1979). After layer separation (1cm), all the samples were dried out and calcined. After additional preparation, the solutions were analyzed with an atomic-absorption spectrophotometer (AAS-3, Perkin-Elmer 360, 460, 560) in air-propane (Ni, Cu, Co, Zn, Cd, Pb, Mn, Fe, Na, K, Sr, Cr), air-acetylene (Mg, Ca) flame. All the metal concentrations are given in microgram per gram (mkg/g) of dry weight. The freshwater ecosystems pollution level has been assessed by the Hekanson method (Hekanson, 1980) adapted to the European subarctic conditions. The contamination factor (C_f) was calculated as the quotient of the element concentrations in the surface bottom sediments layer (0–1 cm) and the background value in the deepest part of the column (Dauvalter, 1999).

The main object under study was Whitefish (*Coregonus lavaretus L.*). The catches were carried out near the Central manor of the reserve (a feeding area) and in the westernmost part of the lake, in the mouth of the Verkhnyaya Chuna (a spawning area). In total, 777 samples was caught. Catches were carried out by a standard set of gill nets, 25 m long and 1.5 m high, and mash sizes: 16, 20,31,36, 40 mm, made of 0.15 mm-dia nylon monofilament thread for small-cell nets and that of 0.17mm-dia for large-cell nets, which allowed catching fish of 10-46 cm in size. Each net was fixed separately from the other in the littoral zone at right angle to the shore and in the profundal zone, up to 10 nets in one series.

Each individual was analyzed for weight, length according to Smith, and for the standard length, fatness, the degree of stomach filling. Maturation of gonads was determined visually in accordance with the standard field methods (Pravdin, 1966). The age was determined by scale. To assess the long-term alternations of whitefish population, archive materials and publications of the Lapland biosphere reserve were used (Vladimirskaya, 1950, 1951, 1956; Reshetnikov, 1962, 1963, 1964 a,b, 1966, 1967, 1975). The state of the whitefish organism has been analyzed by patho-morphological studies (Arshanitsa and Lesnikov, 1987; Kashulina, *et al.*, 1999; Reshetnikov, *et al.*, 1999). The indivuduals were dissected after a short period of time after catch. Special attention has been paid to outer change (the cover color, presence of mucus, bones deformation). In gill analyzing, assessment was made of gill coloration, the presence of mucus and necrotic foci, and the form of rakers. In analyzing the inner organs (liver, kidney, gonads), assessment was made of their size, form, consistence, the presence of hemorrhages and necrotic foci development. To determine the Cu and Ni content in organs and tissues, 10-15 individuals, of the equal size, were selected. Liver, kidney and gills were sampled. The individuals selected were dissected and sampled with knives, scalpels and forceps made of stainless steel. To be further analyzed, the organ samples were frozen. In laboratory, the samples were dried to the constant weight at 90 ^oC, after that the organic matrix was taken out in the concentrated nitrogen acid solution in a microwave decomposition system (Multivave 3000, Anton Paar, AUSTRIA) with further filtration. The Cu and Ni content in gills, liver and kidney was determined by atomic absorption spectroscopy with atomization in flame or graphite tubes using Perkin-Elmer 5000 with a graphite furnace (HGA-400). All the metal concentrations are given in microgram per gram (mkg/g) of dry weight with detection limit of 0.02 mkg/g for Cu and 0.05 mkg/g for Ni. The sample solutions investigated for heavy metals content have been compared with certified standard sample Fluka Chemie GmbH, Switzerland. The quality control was realized using standard sample DORM-2.

Statistical analysis

The reliable difference in biological indices and that in the Cu and Ni concentration in organs and tissues of whitefish was statistically interpreted using the t-criterion.

RESULTS & DISCUSSION

The precipitation analysis has shown that the amount of sulphates, nickel and copper deposited in the lake catchment area annually (on the average over a long-term period) accounts for 1.7, 17.1 and 18.8 tons. The model calculation of long-term load in 1980-2001 has revealed considerable pollutants intake into the Lake Chuna (Table 1). According to the main hydro-chemical indices, the lake is characterized as an oligotrophic ultra-fresh water body. The hydro-chemical composition of water in Lake Chuna is affected by long-term drainage of heavy metals and aluminium from the catchment area, which is due to air-borne industrial emissions from Severonikel copper-nickel smelter. As a result, the hydro-chemical water composition has changed greatly to become typical of air-borne industrial pollution, with the water composition characterized by seasonal variations in the dynamics of pollution supply. In winter, there is a great amount of acidifying agents and heavy metals accumulated in the snow cover during 7-8 winter months. In spring, due to intensive snow melting, these pollutants drain into the lake. Seasonal pH-decrease and heavy metals concentrations fluctuations are due to a considerable input of acid-forming agents in this period (Table 2). Despite the relatively stable Cu and Ni concentrations in Lake Chuna (Table 2), the seasonal dynamics data on the weighted mean of these elements concentration in Lake Gornoe (from where the Chuna originates to flow then into Lake Chuna) demonstrate dramatic increase in these elements concentration in the lake water in spring flood (Fig. 2). The bottom sediments have been analyzed to show a considerable increase in the major (Cu, Ni) pollutants concentration in sediments, from bottom to top. The metals concentration in the upper layers of sediments which were produced by the "industrial" period, exceed twice, and even more, that of the deeper layers which are of the background level. The values of contamination factor were the maximum ones in the eastern (the widest) part of the lake, which was earlier referred to as a feeding area (Table 3). It is likely connected with the fact that this area is characterized by less intensive flowage. High levels of bioaccumulation of Cu and Ni in whitefish organisms are likely to be due to the fact that whitefish inhabits the feeding area for a greater part of the year and, according to its feeding peculiarities, lives near the bottom.

The studies have revealed that the eastern and widest part of the lake is less running, shallow and generally the most favorable for whitefish feeding. The westernmost part of the lake, where the Chuna River flows into it, is deep and is inhabited by mature fish of elder age-groups participating in or non-spawning in the year. This area was defined as a spawning zone.Lake Chuna is inhabited by sparsely rakered whitefish, with the number of gill rakers from 18 to 30. The whitefish is of small size. The mean weight is 258 g, the mean length AC is 28.5 cm. The maximum weight and length AC are 916 g and 41.2 cm, respectively. Juvenile fish made up 2.1% of the catch. These were fish at the age of 1+ and 2+, whose mean weight and length AC are 39 g and 14.2-18.8 c, respectively. All the juvenile individuals were caught in the eastern shallower part of the lake that is a feeding area. The whitefish of younger age groups, 1+ - 3+, were caught in a practically equal proportion. Over a 50-year period, the age structure of whitefish population of Lake Chuna has undergone considerable changes, i.e. the number of the age groups has decreased. The mean age of the population has decreased due to lifetime reduction and increase of the share of younger age groups. According to the early 1960s studies, whitefish population accounted for 13-16 age- groups and the most numerous was fish at the age 6+ (Vladimirskaya, 1951; Reshetnikov, 1996). The maximum age of the current whitefish population is 10+ and the most numerous is fish at the age 5+. Moreover, there were found only single individuals at the age of 8 years (Fig. 3). At present, the number of fish over 5+ accounts for 38.8%, while in the 1960s, this index was much higher (64.5%) (Table 4). Thus, young fish dominated in the catch. The mean size characteristics of whitefish have not significantly changed over the last decades, accounting for 28.6 cm and 260 g against 29.0 cm and 275 g, in the 1960s (Reshetnikov, 1962). Though, at present, the size of whitefish has decreased in old age groups (Table 5). It necessary to note that whitefish of the same size is of a lower weight compared to the earlier data, which can also be indicative of changes' having taken place, which in turn can be explained by lesser fish fatness (Fig. 4).

The comparison of reproduction features of whitefish in the lake has also revealed serious changes. That the whitefish inhabiting the northern water bodies misses spawning is a well known fact, which is due to a short vegetation period in water bodies and to the age and sexual composition, and the feeding conditions (Reshetnikov, 1967, 1980). The current whitefish population participates in spawning at the age of 4+. The minimum size of the fish spawning for the first time, is 23.2 cm/ 142g and 28.0 cm/225 g for male and female fish, respectively. The earlier data (Reshetnikov, 1965) show that at the age of 4+ it was only single male whitefish that became matured, and that the minimum size of the fish spawning for the first time, was 28.5 cm /250 g and 29.2 cm/300 g for male and female, respectively.

The early mass maturation took place at older age when fish was of a larger size, with weight difference being greater against size ones (Fig. 5). This fact is indicative of rejuvenation of the matured part of the population.

Table 1.Air-borne industrial pollutants load on the Lake Chuna ecosystem (tones) during 1980 – 2001 years

	SO_4^{2-}		Ni		Cu	
	Total (1980-2001)	average annual	Total (1980-2001)	average annual	Total (1980-2001)	average annual
Fallouts to catchments, tons	37700	1700	376.4	17.1	412.9	18.8
Hydro-chemical drainage , tons	22600	1027	225.8	10.3	247.7	11.3

Table 2.Some hydro-chemical indices for Lake Chuna (sampling sites: 1 – a feeding area, 2 – a spawning area)

Point of sampling	Date	pH	Alkalinity µeq/L	Al µg/L	Fe	Cu	Ni	Zn	Mn
Chuna Lake 1 (surface)	12.09.00	6.87	106	26	8.7	1.1	1.1	1.2	0.5
Chuna Lake 2 (surface)	12.09.00	6.90	106	56	45.6	1.2	1.4	0.6	2.3
Chuna Lake 1 (surface)	30.10.00	7.00	116	50	13.0	1.5	2.2	1.9	1.1
Chuna Lake 1 (surface)	18.12.00	7.00	135	76	23.0	1.7	1.9	2.0	0.5
Chuna Lake 1 (bottom)	18.12.00	6.84	117	32	20.0	1.3	1.5	0.7	0.3
Chuna Lake 1 (surface)	05.02.01	6.86	175	27	28.0	2.0	2.2	1.6	0.9
Chuna Lake 1 (bottom)	05.04.01	6.93	195	28	14.0	1.9	2.0	6.0	1.4
Chuna Lake 1 (surface)	10.05.01	5.96	9	12	12.0	1.1	1.9	1.1	0.1
Chuna River	25.05.01	6.96	144	38	38.0	1.4	2.2	1.2	3.1
Chuna Lake 1 (surface)	31.05.01	7.02	159	52	34.0	1.7	1.5	2.7	3.1
Chuna Lake 2 (surface)	31.05.01	7.02	165	42	39.0	1.5	2.2	2.2	2.9

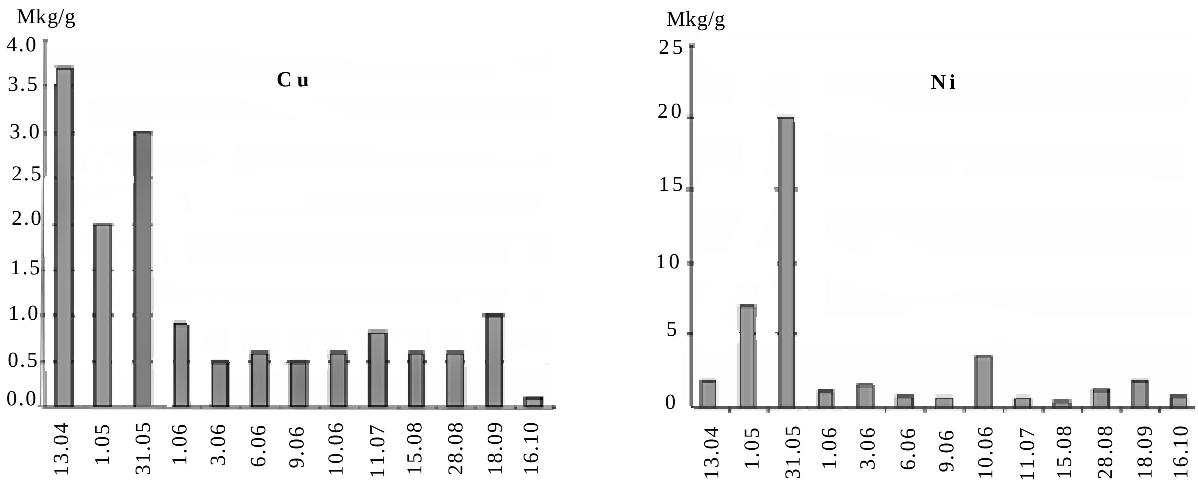


Fig. 2. Seasonal change in the weighted mean of the Cu and Ni concentration in Lake Gornoe in 1997 (Kashulin, *et al.*, 2007)

Table 3.The values of contamination factor (C_f) of bottom sediments in Lake Chuna

Area	Cu	Ni
west part of the lake (spawning area)	1.7	1.8
central part of the lake	1.5	1.9
east part of the lake (feeding area)	3.5	5.8
east part of the lake (feeding area, near Central administration of reserve)	10.4	29.2

Among the whitefish selected at the spawning area in autumn, there was a significant amount of non-spawning individuals that year. The number of non-spawning individuals in the matured part of the population of 5+ and older age accounted for 34-55% (Table 6). Among those who have missed spawning dominated female fish. It has been noted earlier that the whitefish from Lake Chuna would spawn every year (Vladimirskaya, 1951). Later, 14 % of the matured population was represented by non-spawning individuals (Reshetnikov, 1966, 1980). At present, the share of non-spawning whitefish is as great as 38%. The change recorded in whitefish population inhabiting Chuna Lake, under normal reproduction (no commercial fishing), could have been resulted from long-term air-borne industrial pollution. At present, the sex composition of the population has also changed, if compared to the 1950-60s data, according to which, in the early 1950s, male fish dominated over female fish by factor of 3.4. Later, in the 1960s, the number of male fish was twice as many (1.97:1). At present, this proportion is 1:1. On the whole, in the catches of spawning and feeding areas, female fish dominate by factor of 1.5. It should be noted also that in the younger age groups the number of female and male fish is the same. Among the fish at the age of 4+ and 5+ male fish generally dominate. But at the age of 6+ and older female fish dominate in the population, but among the fish older than 7 years, male individuals are single or absent. This is probably connected with higher death rate of male fish of older age groups. The pollution processes have far-reaching effects on the representatives of aqueous ecosystems. For instance, in case with whitefish sampled from Lake Chuna, these effects are clearly observed during decades. Beside the change in the whitefish population, recorded also was true decline of the average size-and-weight values of other fish species over the recent decades (Fig. 6).

Table 4. Percentage ratio of fish of elder age-groups in the whitefish population in Lake Chuna, according to literature and own data (in % of the catch)

age, yrs	period of researches	
	1961-1962	2000-2001
5+	26.9	34.9
6+	38.2	26.9
7+	16.1	10.0
8+	6.3	1.1
9+	2.0	0.4
10+	0.8	0.4
11+	0.7	-
12+	0.4	-
15+	0.1	-

Pathological changes of fish

Ranked the first among the pathological changes of whitefish of Lake Chuna are the changes in liver related to granular and fat degeneration of parenchyma, focal haemorrhages manifesting themselves in change of color and form of the organ. Kidney pathologies included changes of the organ's structure, water retention, focal necrosis which were visually identified as granulation and connective-tissue expansions in the tail part. Change of gills most often included necrosis of gill epithelium and the so called "anemic ring" (~11.8%) (Fig. 7).Pathologies of other organs were visually identified in single cases. Scoliosis was found in 1.8% of the fish. Whitefish gonads developed practically without any visible anomalies. On the whole, among the fish in the catches of 2000-2001 only 1% was healthy. In the course of studies there was one case of stones in kidney or nephrocalcitosis recorded. It should be noted that pathologies of liver and kidney of whitefish were more typical for younger (under 3+) and older (over 7+) age groups.

It is likely connected with the fact that fish of younger age groups is to a greater extent sensitive to the toxicants effect. As for the fish of older age groups, its mechanism of detoxication is more energy-consuming, which intensifies pathological changes of organs.The analysis of Cu and Ni concentrations, the main pollutants in the catchment area of Lake Chuna, was based on the results of seasonal observations during the year. The highest Cu concentrations were found in liver of whitefish of Lake Chuna. The maximum mean Cu concentrations throughout the study period accounted for 102.8 mkg/g dry weight, in some individuals, the Cu concentrations accounted for 434 mkg/g dry weight. Kidney comes next in the mean copper accumulation – 7.1 mkg/g dry weight. The Cu concentrations in gills was 27 times less than that in liver (Fig. 8). On the whole, the Cu concentrations in tissue of whitefish showed high variability.

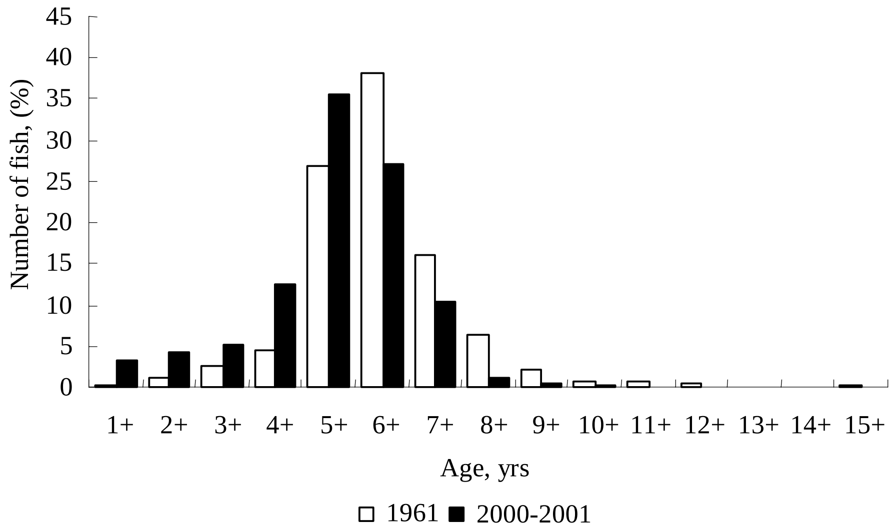


Fig. 3. Whitefish age distribution in Lake Chuna in the 1961 and 2000-2001 catches

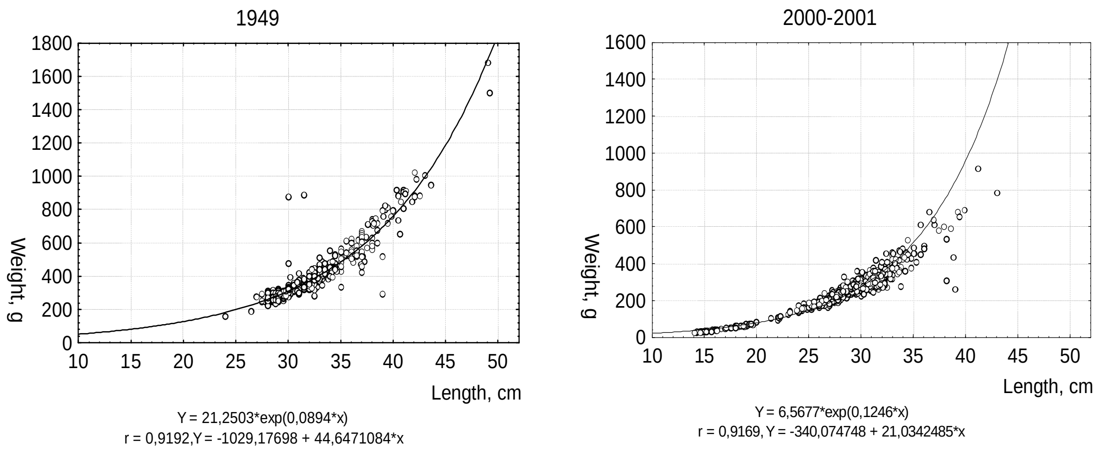


Fig. 4. Whitefish size-and-weight distribution in Lake Chuna in the 1949 and 2000-2001 catches

Table 5.Comparative whitefish size-and-weight indices for older age-groups, according to the literature and own data

age, yrs	indexes	period of researches	
		1949-1950	2000-2001
5+	length, cm	25.2	29.6
	weight, g	279	271
6+	length, cm	28.4	30.4
	weight, g	304	300
7+	length, cm	30.3	32.2
	weight, g	358	360
8+	length, cm	31.8	34.2
	weight, g	467	407
9+	length, cm	33.6	36.9
	weight, g	525	607
10+	length, cm	35.4	37.8
	weight, g	768	640

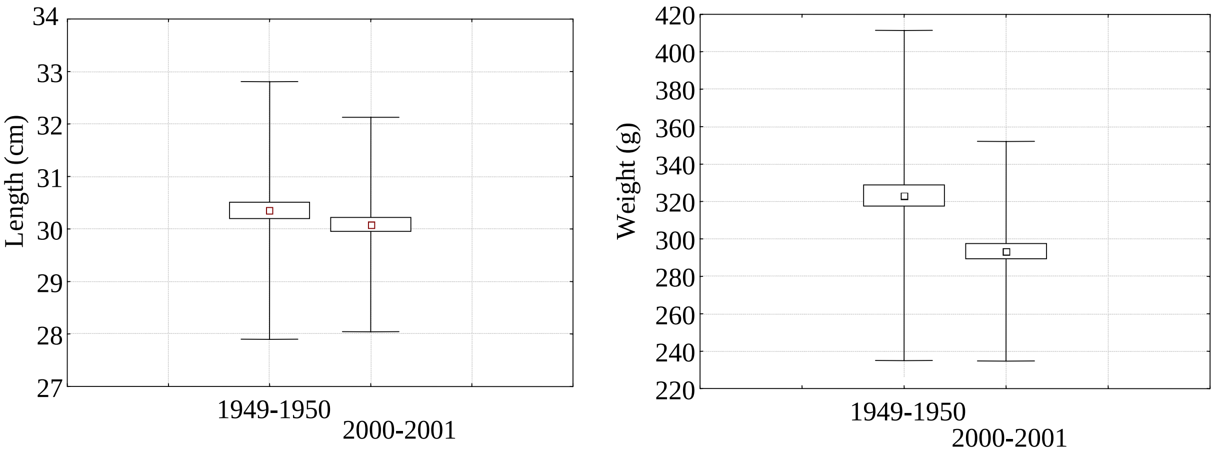


Fig. 5. Comparative average size-and-weight values of the matured whitefish population

□ – Mean, ◘ – ±SE, I – ±SD, ° – Outliers, * – Extremes

Table 6.The number of non-spawning individuals (% of the number of fish in the age group, n=303)

age, yrs	non-spawning individuals, %
5+	34
6+	36
7+	55
8+	40
9+	50

Compared to kidney and liver, the Cu concentrations in gills were the least (liver>kidney>gills). Nevertheless, the distribution of Cu concentration in gills and kidney exhibited some common trends. The highest Cu concentrations in liver, kidneys and gills of whitefish fell on October (Fig. 8). During the following months the concentrations decreased, which is likely due to the end of the feeding period before spawning and due to work of detoxication mechanisms, which decrease Cu concentrations in the organism. In winter, however, the Cu concentrations in liver increased (Fig. 8). Besides, seasonal dynamics of the Cu concentrations in liver showed considerable variations. The Cu concentrations in liver of whitefish were the highest in October and January, accounting for 102.80 and 94.92 mkg/g dry weight, respectively (Fig. 8). The mean Cu concentrations in gills and kidneys were more than 10 times less (Fig. 8). It should be noted that the Cu concentrations in water during the year have not practically changed, being equal to 2 mkg/L. The differences in the Cu concentrations in whitefish organs in autumn were often statistically more reliable compared to other months. On the whole, during the year, the differences of minimum and maximum values of the Cu concentrations in liver, kidneys and gills were statistically reliable ($p<0.05$).

Nickel is one of the major pollutants of aquatic ecosystems of the Kola North, which is discharged by mining enterprises. As a rule, the highest values of Ni concentrations in fish were recorded in kidneys. The concentrations in other organs were lower, being distributed as follows: kidney>gills>liver (Table 7). The Ni concentrations in whitefish gills were at least 4 times less compared to that in kidneys. The highest mean Ni concentrations in kidneys accounted for 6.7 mkg/g $_{\text{dry weight}}$ (Fig. 9). The maximum value accounted for 16.5 mkg/g $_{\text{dry weight}}$ in September. Then, after the two-fold reduction of the Ni content in October, its concentrations slowly increased till July. In summer, however, the Ni concentration in kidneys of whitefish lowered against that recorded in the beginning of autumn. The metal concentration distribution differed reliably through months – the same as it has been observed for the Ni distribution in gills. During the year, the maximum and minimum values differed reliably only for liver and kidneys ($p<0.05$). The distribution of heavy metals in whitefish organs was characterized by two peaks of their concentrations, as a rule, twice a year. The peaks of Cu concentrations fell on autumn-winter and summer periods. The levels of copper concentrations in fish organs show a non-uniform character of its intake into the organism with food and via contact surfaces (gills and skin).

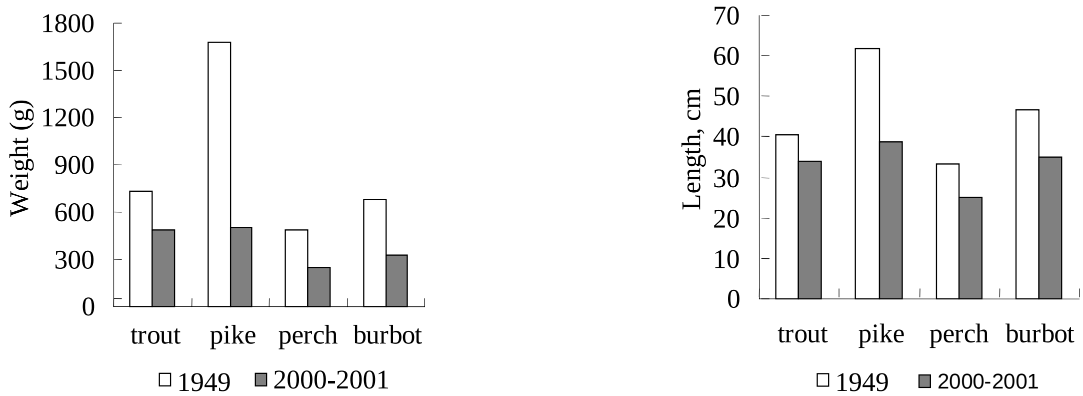


Fig. 6. The average size-and-weight indices of fish in Lake Chuna, according to the earlier studies (Vladimirskaya, 1951) and own data (2000-2001)

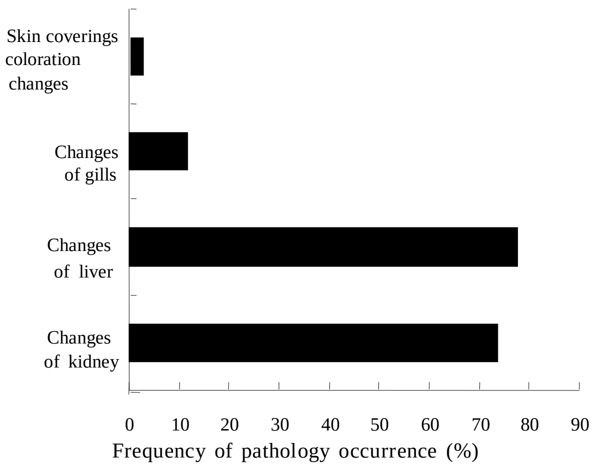
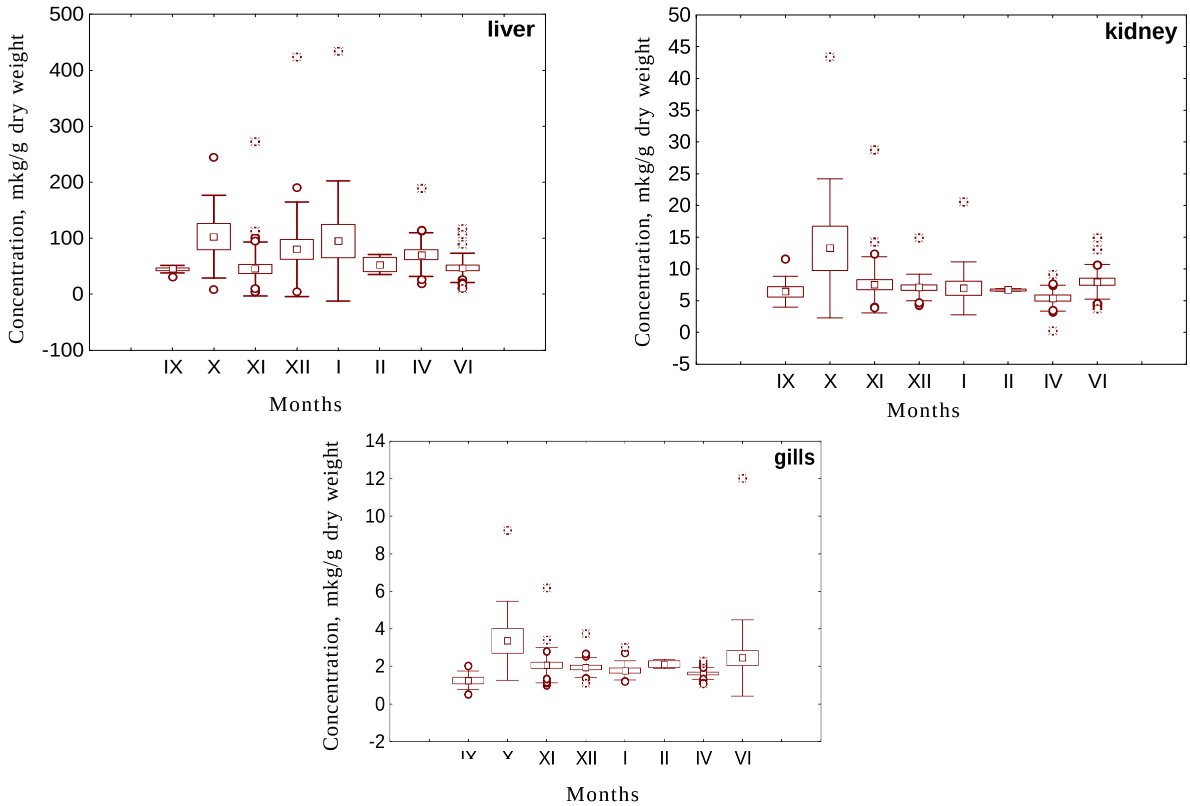


Fig. 7. Frequency of occurrence of pathological changes of whitefish in the Lake Chuna in the catches of 2000-2001

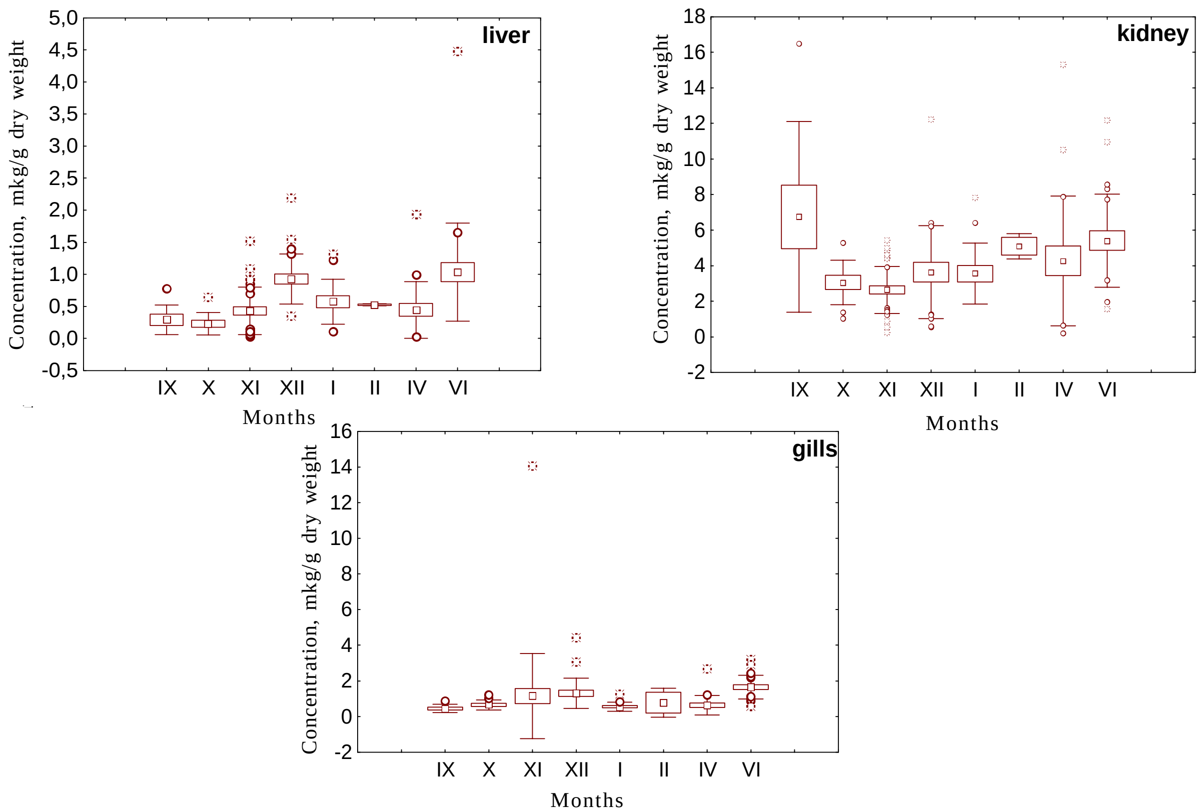
It is known that fish can avoid unfavorable environment, including the areas with high concentrations of pollutants. Among the fish studied, there were some individuals with abnormally high copper concentrations in all organs. This phenomenon was recorded throughout the whole study period, being particularly typical for autumn – winter period (Fig. 8, 9). The reason for this may be high level of metal input into the organism with food in summer, which is a feeding period, and, on the whole, a higher exchange level. With the feeding rate decreasing in winter, excessive toxicants can be removed from organism by biochemical processes. Metals are known to be primarily absorbed by mucus membranes (gills, digestive tract and skin). Then these are transported from gills and digestive tract into blood to be distributed in various parts of the body. Muscles, as a rule, accumulate Cu and Ni in fewer quantities. Liver is an organ with a higher copper accumulative capacity, kidneys accumulate nickel (Bradley and Morris 1986; Graehl et al., 1985), which is confirmed by the present study.

Variation and high concentrations of heavy metals in organs and tissues of whitefish in autumn may be caused by cyclic change in temperature conditions in the water body. The precipitation is known to increase in autumn, which is followed by more intensive outwashing of pollutants from the atmosphere and the catchment area. Analogous but more intensive process is also pollutants intake into water bodies in spring snowmelt. Of great danger is the increase in water acidity, which is able to stimulate partial heavy-metal release from bottom sediments and increase their mobility. Of significance is also the fact that whitefish under study have a benthic type of nutrition. An increase in water temperature in summer can also affect the fish because, as the temperature rises the metal activity and mobility rise sharply. Besides, the increase of water temperature results in intense gill ventilation, due to increased oxygen need, related to metabolic needs and/or decrease of oxygen concentrations in water (Douben, 1989; Heath, 1987). In the period of stable ice cover, low oxygen concentrations in water stimulate intensive respiration, which may increase metal concentrations in gills. Alongside with it, in case of low oxygen content in near-bottom layers, it is possible for heavy metal to partially release from bottom sediments (Dauvalter, 1998). A comparative analysis of Cu and Ni concentrations in organisms of brown trout (predator, inhabits



□– Mean, ▫– ±SE, I– ±SD, ° – Outliers, * – Extremes

Fig. 8. Seasonal dynamics of Cu concentrations (mkg/g $_{\text{dry weight}}$) in liver, kidneys and gills of whitefish in Lake Chuna



□– Mean, ▫– ±SE, I– ±SD, ° – Outliers, * – Extremes

Fig. 9. Seasonal dynamics of the Ni concentrations (mkg/g $_{\text{dry weight}}$) in liver, kidneys and gills of whitefish in Lake Chuna

Tabe 7. The Cu and Ni concentrations in whitefish organs in Lake Chuna during the year (mkg/g $_{dry\ weight}$).

		Months							
		September	**October**	**November**	**December**	**January**	**February**	**April**	**June**
Cu									
gills	Mean±SE	1.25±0.17	3.36±0.66	2.06±0.16	1.94±0.11	1.78±0.14	2.13±0.17	1.63±0.07	2.45±0.40
	Min–max	0.50–2.04	1.91–9.23	1.00–6.16	1.10–3.74	1.22–3.02	1.96–2.30	1.09–2.30	1.28–12.03
kidney	Mean±SE	6.41±0.81	13.24±3.47	7.52±0.78	7.05±0.44	6.95±1.11	6.67±0.14	5.40±0.46	7.96±0.56
	Min–max	4.43–11.49	5.38–43.36	3.87–28.80	4.31–14.84	3.43–20.54	6.52–6.81	0.21–9.16	3.79–14.94
liver	Mean±SE	44.74±2.61	102.80±23.37	44.93±8.39	80.00±17.63	94.92±29.81	53.11±12.68	70.63±8.96	47.10±5.17
	Min–max	31.07–52.04	9.00–245.00	4.27–272.22	3.71–423.59	36.20–434.05	40.43–65.79	18.21–189.25	10.69–117.20
Ni									
gills	Mean±SE	0.46±0.08	0.65±0.09	1.14±0.42	1.30±0.18	0.55±0.07	0.78±0.58	0.63±0.13	1.65±0.13
	Min–max	0.16–0.88	0.37–1.20	0.16–14.07	0.61–4.41	0.29–1.24	0.20–1.35	0.16–2.66	0.60–3.21
kidney	Mean±SE	6.74±1.79	3.06±0.39	2.64±0.23	3.64±0.54	3.55±0.45	5.09±0.50	4.27±0.83	5.41±0.55
	Min–max	1.79 – 16.47	1.02 –5.29	0.23–5.42	0.57–12.22	1.81–7.85	4.59–5.59	0.21–15.30	1.56–12.21
liver	Mean±SE	0.29±0.09	0.23±0.05	0.43±0.06	0.93±0.08	0.57±0.09	0.53±0.01	0.44±0.10	1.03±0.15
	Min–max	0.09–0.77	0.07–0.64	0.02–1.52	0.35–2.19	0.11–1.31	0.51–0.54	0.03–1.93	0.48–4.48

pelagic zone) and whitefish (benthophage, inhabit profundal zone) of Lake Chuna reliably showed higher Cu and Ni concentrations in whitefish ($p<0.05$). Copper and nickel don't accumulate in food chains; their concentrations depend largely on the load level, which depends on the ecology of species. It should be noted also that metals concentrations in organs of whitefish varied within a wider range, compared to that of trout (Fig.10).

CONCLUSION

The development of the mining complex in the Murmansk region is accompanied by intensive air pollution. Pollutants are able to be transported by air masses to considerable distances from their sources. Having been deposited on water bodies and catchment area surface, the pollutants gradually accumulate in terrestrial and freshwater ecosystems to sub-lethal affect the living organisms.To our opinion, the simplification of the whitefish population structure in Lake Chuna (namely, age groups and lifetime reduction, increased share of younger fish, higher number of non-spawning fish) recorded over a 50-year period of study, has been caused by a long-term impact of small doses of pollutants. The intensified energy exchange induced by the change of the habitat, brings about a higher growth rate and earlier maturation of whitefish and lower size limits (Kashulin, *et al*, 1999; Reshetnikov, *et al*, 1967).

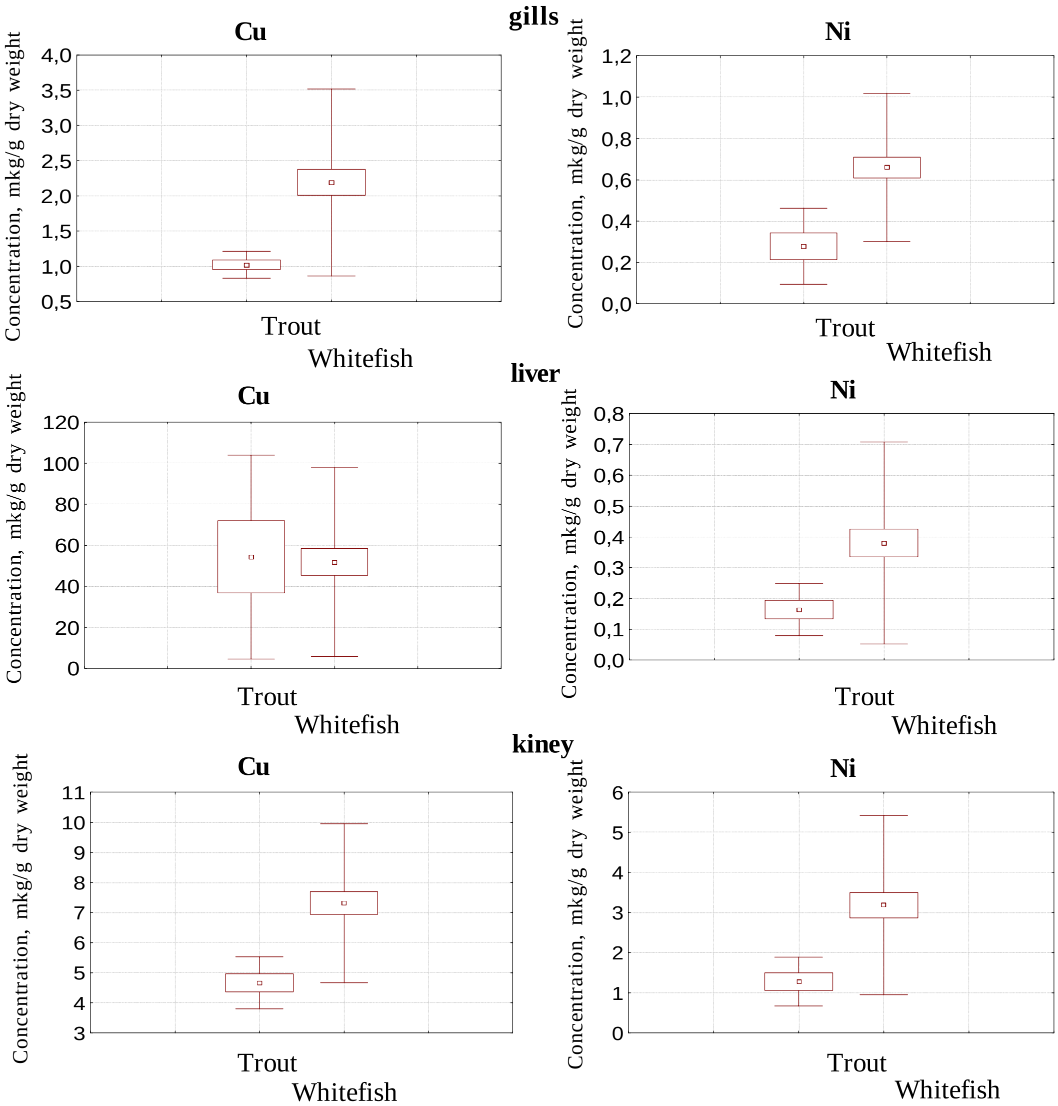


Fig. 10. The Cu and Ni concentrations in organs of trout and whitefish of Lake Chuna (mkg/g dry weight);
□ – Mean, □ – ±SE, I – ±SD, ° – Outliers, * – Extremes

The early maturation of whitefish is likely to be a response of the population to lifetime reduction caused by an increase in environment toxicity. In the existing favorable feeding conditions, the whitefish have higher growth rate, compared to the data of the earlier studies, but its weight rate has reduced. The analysis of some individuals showed that fish have high frequency of pathological changes of organs, particularly, liver and kidneys pathologies. The inner organs pathology development is likely to be a result of metabolic processes violation of the organism and be related to heavy metals accumulative impact. The metal concentration in whitefish organs has been found to widely variation, which is caused by extremely high metal concentration in fish samples. Moreover, it is noted that higher metals concentrations in target organs of some individuals have been interrelated. For instance, the whitefish, with high Cu concentration in liver, had higher Ni concentration in kidney, which is indicative of mutual load of these metals on fish organisms. The peculiarities of nutrition and habitat of whitefish cause higher Cu and Ni concentration in organism, compared to predatory fish species (trout). Despite the metals elimination mechanisms, stable pollutant intake into the fish organism induced by long-term air-borne industrial pollution results in metal accumulation in organs and tissues during the fish lifetime. Despite the absence of economical activities in the reservedterritory in which Lake Chuna and its catchment area are located, its status is not enough to prevent changes in fish populations, which are induced by air pollution. The ecosystems functioning in the impact zone of large industrial complexes requires monitoring over the state and the response of a biological constituent.

ACKNOWLEDGMENTS

The authors of this study accord thanks to the researchers of the laboratory of aqueous ecosystems of the Institute of the North Industrial Ecology problems KSC RAS, who participated in the studies, and also to the directorship of the Lapland biosphere reserve for assistance in preparation and fulfillment of the project.

REFERENCES

AMAP, (1998) Assessment Report: Arctic Pollution Issues. Oslo, Norway.

AMAP, (2003). *Influence of Global Climate on Contaminant Pathways Report.* Oslo, Norway.

AMAP, (2004). AMAP Assessment 2002: Persistent Organic Pollutants in the Arctic. Oslo, Norway.

AMAP, (2005). Assessment 2002: Heavy Metals in the Arctic. Oslo, Norway.

AMAP, (2006). Assessment 2006: Acidifying Pollutants, Arctic Haze, and Acidification in the Arctic. Oslo, Norway.

APHA, AWWA, WPCF (1975). Standard methods for the examination of water and wastewater. 14 Ed. (Washington, D.C: American Public Health Association)

Arshanitsa, N. M., Lesnikov, L., (1987). Pathology-morphological analyses of fish condition if field and experimental toxicological researches. (In V.I. Lukjanenko (Eds.) Methods of ichthyologic researches. (7-9). Leningrad: GosNIORH. (In Russian)

Bradley, R. A., Morris, J. R. (1986). Heavy metals in fish from a series of metal-contaminated lakes near Sudbury, Ontario. Water, Air and Soil Pollut., **27**, 341-354.

Cooley, H. M., Evans, R. E., Klavercamp, J. F. (2002). Baseline measurements of indicators for sub-lethal effects of metals in lake whitefish (*Coregonus clupeaformis*). Arch. Environ. Contam. Toxicol., **43**, 418-424.

Dauvalter, V. A., (1998). Concentration of metals in bottom sediments of acidified lakes. Water. Res., **25** (3), 358-365. (In Russian)

Dauvalter, V. A., (1999) Regularities of sedimentation in water objects of European Subarctic environmental aspects of the problem). Dissertation, INEP KSC RAS

Douben, P. E. T. (1989). Uptake, elimination of waterborne cadmium by the fish *Noemacheilus barbatulus L.* (stone loach). Arch. Envoron. Contam. Toxicol., **18**, 576-586.

Hakanson, L., (1980). An ecological risk index for aquatic pollution control-a sedimentological approach. Water Res., **14**, 975-1001.

Heath, A. G., (1987). Effect of waterborne copper or zinc on the osmoregulatory response of blue gill to a hypertonic Na-Cl challenge. Comp. Biochem. and Physiol., **88**, 307-311.

Kashulin, N. À. (1995). Fish populations condition in small lakes of the Kola north forest zone under aerotechnogenic pollution. (In T.I. Moiseenko & V.A. Jakovlev (Eds.), Problems of chemical and biological monitoring of ecological state of water of the Kola north (pp. 120-143). Apatity: KSC RAS.) (In Russian)

Kashulin, N. A., Lukin, A. A. and Amundsen, P. A., (1999). Fish of subarctic freshwater systems as bio-indicators of industrial pollution, (Apatity: KSC RAS) (In Russian)

Kashulin, N. A., Dauvalter, V. A., Sandimirov, S. S., Ratkin, N. E., Terentjev, P. M., Koroleva, I. M., Vandysh, O. I.

and Kudravtseva, L. P., (2007). Anthropogenic changes of lothic ecosystems in the Murmansk region. The Chuna lake-river system under conditions of air pollution. (Apatity: KSC RAS) (In Russian)

Klaverkamp, J. F., (2002). The accumulation, distribution, and toxicological effects of dietary arsenic exposure in lake whitefish (*Coregonus clupeaformis*) and lake trout (*Salvelinus namycush*). Comp. Biochem. and Physiol., **131**, 73-91.

Klaverkamp, J. F, Wautier, K., Baron, C. L., (2000). A modified mercury saturation assay for measuring metallothionein. Aquat. Toxicol., **50**, 13-25.

Lurje, J. J., (1984). Analytical chemistry of manufacturing water. (Moskow: Chimija) (In Russian).

Moiseenko, Ò. I., (1997). The theoretical base of anthropogenic loads regulation on Subarctic waterbodies. (Apatity: KSC RAS) (In Russian)

Moiseenko, Ò. I., Dauvalter, V. A., Lukin, À. À., Kudravtseva, L. P., Iljashuk, B. P. Iljashuk, E. A., Lukin, A. A., Sandimirov, S S., Kagan, L. Ja., Vandysh, O. I., Sharov, A. N.,. Sharova, Ju.N. and Koroleva, I. M., (2002). Anthropogenic modifications of the Imandra Lake ecosystem. (Moscow: Nauka) (In Russian)

Moiseenko, Ò. I. and Jakovlev, V. A., (1990). Anthropogenic transformations of water ecosystems in the Kola North. (Leningrad: Nauka) (In Russian)

Mokrotovarova, O. I. (2003). Long-term dynamics of industrial centers air pollution in Murmansk region. (In N.A. Kashulin and O.I. Vandysh (Eds.), Kola peninsula on the threshold of the third millennium: ecological problems, (5-12). Apatity: KSC RAS.) (In Russian)

Morozov, N. P., (1979). About a ratio of microelements migration's forms in rivers, bays, seas and oceans. Geochem., **8**, 1259-1263. (In Russian)

Munkittrick, K. R. & Dixon, D. G (1989). Use of white sucker (*Catostomus commersoni*) populations to assess the health of aquatic ecosystem exposed to low-level contaminant stress. Can. J. Fish. Aquat. Sci., **46**, 1455-1462.

Pravdin, I.F. (1966). Fish researches instruction. (Moscow: Pishevaja prom) (In Russian)

Ptashynski, M. D., Kleverkamp, J. F., (2002). Accumulation and distribution of dietary nickel in lake whitefish (*Coregonus clupeaformis*). Aquat. Toxicol., **58**, 249-256

Ratkin, N. E., (2006). Regularities and levels of air pollution of landscapes of Murmansk region and Scandinavian North. Dissertation, Institute of the North Industrial Ecological Problems

Reshetnikov, Yu. S., (1962). About a systematic position of whitefishes of Lapland. (Monchegorsk: Lapland reserve report) (In Russian)

Reshetnikov, Yu. S., (1963). Variability and polymorphism of Coregonid fishes connected with their peculiar feeding habits in northern water-reservoirs. Dokl. AN USSR, v. 152, No.6, 1465-1466. (In Russian)

Reshetnikov, Yu. S., (1964a). Feeding of different whitefish intraspecific morphs from different lakes of Lapland reserve. Voprosy Ikhtiologii, **4**(4), 679-694. (In Russian)

Reshetnikov, Yu. S., (1964b). Particularities of fish maturation in northern waterbodies. (Monchegorsk: Lapland reserve report) (In Russian)

Reshetnikov, Yu. S., (1966). Particularities of growth and maturation of whitefish in waterbodies of the North. (In G.V. Nikolskiy & Ju.E. Lapin (Eds.), Regularities of fishes population dynamics in White sea and its basin (93-155). Moscow: Nauka). (In Russian)

Reshetnikov, Yu. S., (1967). About a reproduction cyclicity of whitefishes. Voprosy Ikhtiologii, **7** (6), 1019-1031. (In Russian)

Reshetnikov, Yu. S., (1975). About a systematic position of coregonid fishes. Zool. Jurn., **54** (11), 1656-1671. (In Russian)

Reshetnikov, Yu. S., (1980). Ecology and systematic of coregonid fishes. (Moscow: Nauka) (In Russian)

Reshetnikov, Yu. S., (2003). Atlas of Russian freshwater fishes. In two volumes. (Moscow: Nauka) (In Russian)

Reshetnikov, Yu. S., Popova, O. A., Kashulin, N. A., Lukin, A. A., Amundsen, P. A. and Staldvik, F. J., (1999). Estimating the favorable state of a fish community using morphopathologic analysis of fishes. Uspehi sovremennoi biologii, **119** (2), 165-177. (In Russian)

Semenov, A. D., (1977). The instruction for chemical analysis of dry land surface water. (Leningrad: Gidrometizdat).

Sidorenko, G. I. and Itskova, À. I., (1980). Nickel. Hygienic aspects of environmental protection. (Moscow: Medicina) (In Russian).

Skogheim, O. K., (1979). Rapport fra Arungenprosjectet. (Oslo: As-NLH.).

Veshnjakov, I. A, Kalabin, G. V. and Makarova, T. D., (1999). Ecological atlas of Murmansk region. (Apatity: KSC RAS) (In Russian)

Vladimirskaja, Ì. I., (1950). A fauna of fishes of Lapland reserve. (Monchegorsk: Lapland reserve report) (In Russian)

Vladimirskaja, Ì. I., (1951). Fishes of lakes of the central part of Kola peninsula. (Monchegorsk: Lapland reserve report) (In Russian)

Vladimirslaja, Ì. I., (1956). Whitefishes of the Imandra Lake basin. Voprosy ihtiologii, **6**, 136-148. (In Russian)