Zooplankton and zoobenthos of subarctic Imandra Lake following water quality improvements, Kola Peninsula, Russia

Yakovlev Valery
Kazan State University, 420087, Kazan, Russia; Valery.Yakovlev@ksu.ru

Abstract
The composition, species richness and abundance of zooplankton and zoobenthos communities were studied in highly contaminated by the heavy metals and other toxic and non-toxic matters Monche Bay in large subarctic Imandra Lake (northwestern Russia) based on data collected between 1978 and 1996. The obvious degradation of communities (quite often destruction of all macrozoobenthos) related to increase of contamination from "Severonickel" smelters has been documented in the period 1980-1985s. The tolerant to pollution, mainly circumpolar distributed species, such as cyclopoids, *Bosmina* spp., *Asplanchna priodonta*, *Keratella cochlearis*, *Chironomus* and *Procladius* chironomids were common in polluted waters. From the mid 1980s, owing to introduction of purification system, and in 1990s, due to reduction of industrial operations it were some evidence of shifts in composition of dominant groups, increase of species richness, number and biomass of communities. Sensitive, before earlier-existing species, such as crustacean *Leptodora kindtii*, *Bytothrephes cederstromii*, *Heterocope*, *Mysis oculata*, *Monoporia affinis*, *Heterotrissocladius* spp. and gastropods have been found in samples from open lake areas, remote from sewage water discharge site, but we found no recolonization or more frequent occurrence in polluted Monche Bay.

Introduction

Long-term contamination of Imandra lake has led to accumulation of significant amount of heavy metals in water and lake sediments (Chijikov, 1980;, as well as to biota communities degradation (Moiseenko and Yakovlev, 1990). The most dramatic ecological state was observed in Monche Bay, which has been polluted from end of 1930s with sewage waters from the "Seveonickel" smelters.

Northern oligotrophic lakes distinguished by rather low concentrations of nutrients and organic matters, and more vulnerability of ecosystems in comparison with lakes located at more southern geographical zones (Yakovlev, 2002a). For example, eutrophic and mesotrophic lakes with rather high biological productivity are capable to sustain higher loads of heavy metals.

The most dramatically degradation of biota communities, related to contamination, has been documented for the Imandra Lake in the period 1980-1985 (Moiseenko, Yakovlev, 1990). A certain degree of water quality improving was occurred in period 1985-1995, which accompanied by some biological recovery in planktonic and benthic communities (Yakovlev, 2001). The evidences of biological recovery in biota communities after the reduction in the emissions of SO_2 and heavy metals have been shown for small lakes in Canada (Hutchinson and Havas, 1986; Keller, Pitblado, Conroy, 1986; Gunn, Keller, 1990; Arnott et al., 2001). However Canadian lakes were acidified and changes in the biological communities occurred when inputs of sulphur and metals were reduced. In our case, high water turbidity and significant contents of organic and nutrient matters accompanied the contamination by heavy metals.

Our objectives in this study were: (1) to describe zooplankton and benthos communities in highly contaminated area of subarctic Imandra Lake, and (2) to assess responses of biota communities to changes in the water quality.

Site Description

Imandra Lake is a large lake (area, 812.5 km^2, maximum depth, 64 m, volume, 10.9 10^6 m^3) located west along the Khibiny Mountains in the Murmansk Region, Russia ($67^0$40 N, $33^0$00 E). The lake was oligotrhophic (Chijikov, 1980) and for a long time, until the 1960s, had been known to have a high yield of fish (Moiseenko, Yakovlev, 1990). Monche Bay, which has been polluted for more than six decades with sewage waters from the "Severonickel" smelters and municipal sewage waters from the Monchegorsk town purification plant, is a narrow gulf 10 km long (Fig. 1).

The annual mean concentrations of Ni in the lake water reached maximum levels 323.8 and 466.3 µg/L, suspended particles, 9.0-11.8 mg/L, TOC, 4.9-4.7 mg/L in 1981-1982s. It was revealed significant ($P < 0.01$) negative Spearman correlation between concentrations of the majority of contaminants in lake water and distance from a source of contamination.

Water quality improvements have been shown to occur rapidly when contamination from "Severonickel" smelters is reduced. Concentrations of heavy metals, suspended particles and TOC all declined significantly ($P < 0.1$) during 5-year period (1985-1992) after introduction of the partial re-use of water systems and with the beginning of economic crisis in Russia from 1990s (Fig. 2).

Material and Methods

The quantitative zooplankton samples from Monche Bay were collected between July and mid-August from 9 stations along the direction of polluted water spreading in 1981, 1986 and 1990. Depending on lake depth, mixed samples were made from depth of 0-5 and 0-10 m. The animals were filtered through a net of mesh size 65 µm. Benthic invertebrates, inhabiting soft sediments were sampled in 1978, 1779, 1981-1983, 1986, 1990-1996 using an Ekman dredge collector at least monthly during the open water period. The generated annual averages of zooplankton and zoobenthos data obtained using weighted mean values. Diversity was estimated using the Shannon-Wiener index (H). Species richness was calculates as the number of species (or higher taxons for the some groups of benthic invertebrates) per one sample. The biological differences in data were examined with Wilkokson-tests. In order to examine relationships between biological data and chemical variables rank correlation analyses were done.

Results and discussion

The laboratory tests performed in the period 1981-1985s showed very high toxicity of the "Severonickel" sewage waters and lake waters taken from Monche Bay for green algae *Scenedesmus quadricauda*, cladoceran *Daphnia magna*, amphipod *Monoporeia affinis* even after 100 times dilution with clean water in acute experiments. Only chironomid *Chironomus dorsalis* has not shown sensitivity and larvae remained alive up to the end of laboratory tests (Moiseenko, Yakovlev, 1990).

Very qualitative poor zooplankton in samples from Monche Bay was presented only by not numerous cyclopoida nauplii and copepodits in Monche Bay, near to pollution waters discharge site in 1980-1985. Predaceous cyclopoids seem to be tolerant to high water turbidity and oxygen depletion (Rivjer and Kurdin, 1982), as well as to heavy metal effects (Yakovlev, 2002a).

Density of zooplankton gradually increased, as well as the relative rotifer and cladoceran abundance along the main direction of polluted water spreading to open Imandra Lake area. It was found significant positive correlation between zooplankton abundance and distance from discharge site ($P < 0.05$). In central part of Monche Bay, where a mixing of the heavy metal contaminated sewage and waters, containing organic materials and nutrients takes place, the highest densities of cladocerans *Bosmina*, rotifers *Asplanchna priodonta* and *Keratella cochlearis*.

In a total, 37 zoobenthos species number found in samples from sublittoral and profundal areas of Monche Bay in 1978-1996. Only one, apparently tolerant-to-pollution species, such as *Chironomus* chironomids occurred in great abundance in communities of Monche Bay, close to the pollution water discharge site with extremely high concentrations of heavy metals in water (Ni > 700 µg/L). In the parts remote from the discharge site, common species were also chironomids *Procladius (Holotanypus)* spp., *Monodiamesa bathyphila* and *Psectrocladius* spp.

The littoral communities were presented by low number of *Psectrocladius* chironomid species, also coleopterans, hemipterans and ceratopogonids (Moiseenko, Yakovlev, 1990; Yakovlev, 2002a).

The degradation of biota communities in Monche Bay was caused by the combined effects of the toxic metals and high water turbidity (Yakovlev, 2001). The zooplankton and zoobenthos species richness, plankton abundance negatively correlated ($P < 0.05$) with concentrations of Ni, Cu, Co, suspended matter in the most dramatic period, in 1981-1985. However abundance of the zoobenthos presented mainly by chironomids, was characterized by positive correlation of pollutants.

Long-term changes in communities

Natural cyclic and succession processes connected with autogenous and allogenous factors define the changes in the biota communities in non-polluted lakes. Long-term changes in communities of Monche Bay occurred as response to changes in pollution impact. Clear evidences, indicating changes in zooplankton and zoobenthos communities following both the water quality worsening or improvement in our study were the shifts in species diversity and species richness, total and relative abundance and biomass of the major taxonomic groups.
Plankton community in Monche bay in 1973 was dominated by rotifers *Keratella cochlearis*, *Polyarthra, Ploesoma truncatum*. The share of cyclopoid species, *Bosmina* and *A. priodonta* became the most important species in samples during 1981-1983. Total plankton species diversity, total number and biomass were higher in 1968-1973 than in 1981 and 1990 ($P < 0.05$; Fig. 3).

It was caused with extinction of some sensitive species typical for Monche Bay before pollution impact. The relative abundance of rotifers declined from 94% to 45%, while the relative abundance of cladoceran increased from 1% to 35% in the period 1968-1990 (Yakovlev, 2001). However it is evident that relative biomass of cladocera group was lowest in 1981 (Fig. 4).

Rotifer *Notholca caudata* were also common in the following samplings. The typical of Imandra Lake, earlier-existing species, such as *Leptodora kondtii, Polyphemus pediculus, Bythotrephes* sp., *Heterocope appendiculata* were found in samplings in the period 1986-1990.
In benthic communities of Monche Bay, the tendency to reduction of species richness owing to extinction of sensitive to water quality worsening species, such as mysid *Mysis oculata*, amphipod *M. affinis*, and other typical inhabitants of northern lakes was marked in 1938-1940 (Dolnick and Stalmakova, 1976; Dengina, 1980). Extremely low species richness, diversity, abundance and biomass of zoobenthos communities in Monche Bay occurred in 1981-1985 (Fig 5).

Approximately 30% of chironomid larvae had the pathological deformations of submentum or antenna in this period (Yakovlev, 2002a). The pathological changes in fish kidney (nephrocalcytosis), diseases in liver and gills, and high heavy metal content in fish and zoobenthos were revealed in 1980s (Moiseenko, Yakovlev, 1990; Yakovlev, 2002b). The complete destruction of all macrozoobenhtos animals in lake area close to "Severonickel" sewage water was documented several times during 1980-1983. The relative biomass of Chironomini in a total chironomid group was higher during 1981-1986. Sensitive to pollution Tanytarsini chironomid species showed the lowest relative biomass in this period (Fig. 6).

The plankton and benthos communities of Monche Bay had begun to recover from pollution effect during the 1985. This process was evident by all communities' characteristics, such as in species composition, diversity and richness, abundance and biomass (Yakovlev, 2001). However, more evident species composition shifts in plankton communities was documented for Swan Lake near Sudbury during initial recovery from acidification (Arnott et al., 2001). In our study, it was more obvious changes in total abundance and biomass of zooplankton and benthos.
The role amphipod *M. afinis* after the more than 30-year's absence for the first time were found in 1990s in the vicinity to the Monche Bay areas, where the concentration of heavy metals was comparatively low. However occurrence of new species or other sensitive to pollution species or before usual in lake species, such as mysid *M. oculata*, gastropods and leeches in Monche Bay was not observed. In middle 90's, the tendency to a degradation of communities again was obvious.
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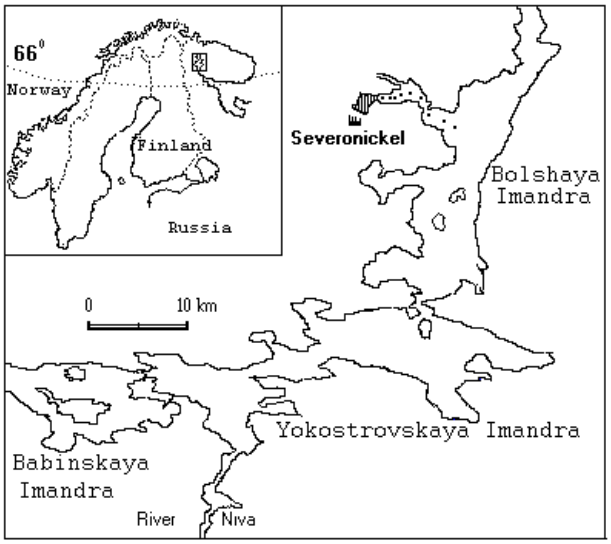

Fig. 1. The the study area in Imandra Lake. Location of the "Severonickel" waste reservoir is shaded. Sampling sites are marked by points.

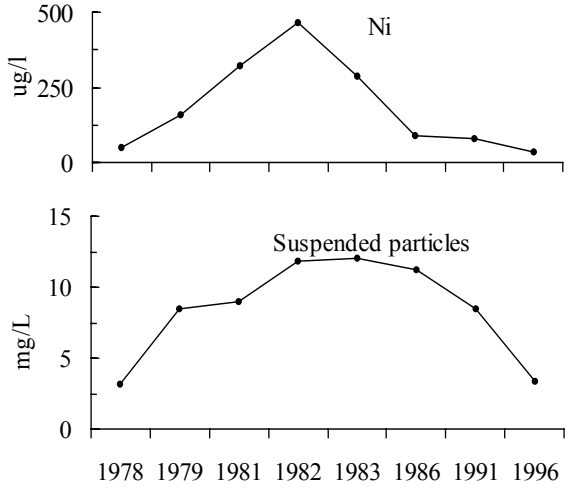

Fig. 2. Mean annual concentration of nickel and suspended particles in the water of Monche Bay.

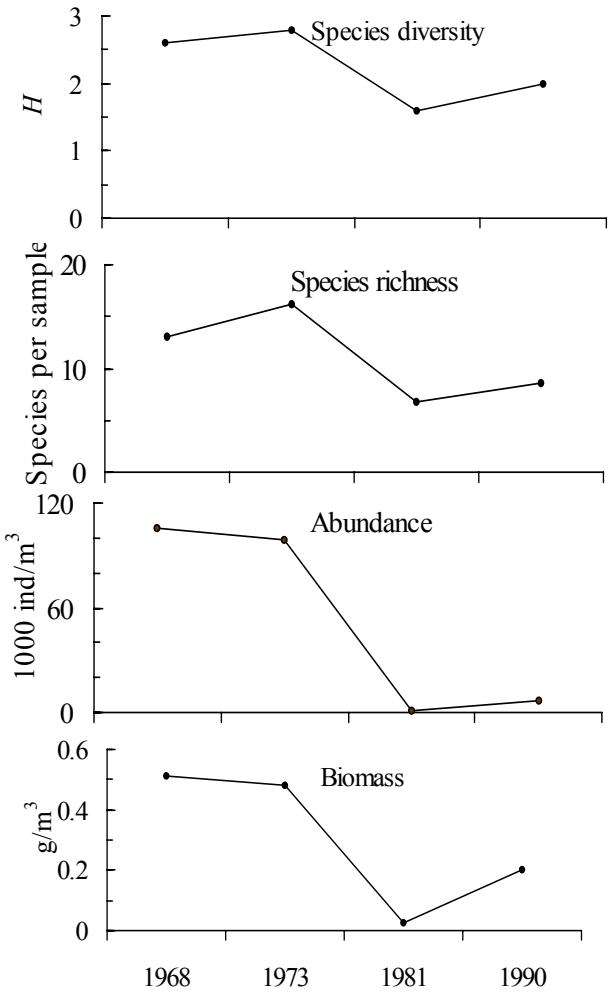

Fig. 3. Mean annual species diversity, richness, total abundance and biomass for zooplankton in Monche Bay.
Data on 1968 from Dolnick and Stalmakova (1976) and on 1973 from Dengina (1980).

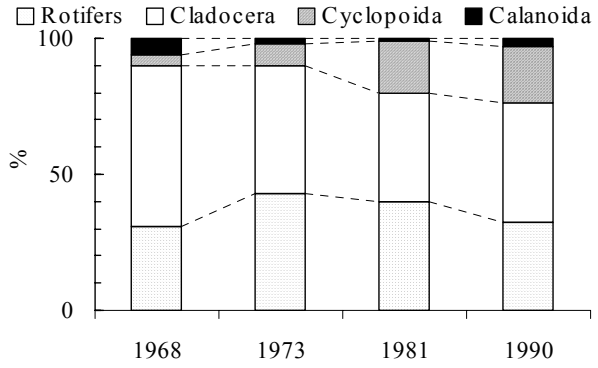

Fig. 4. Mean annual relative biomass of major taxonomic groups for zooplankton in Monche Bay.

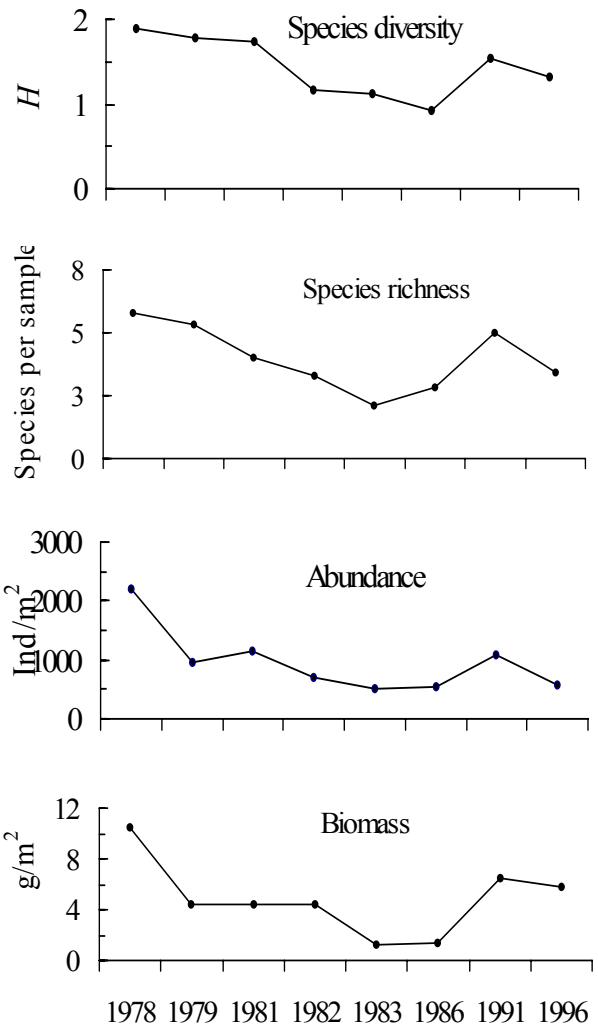

Fig. 5. Mean annual species diversity, richness, total abundance and biomass for zoobenthos in Monche Bay.

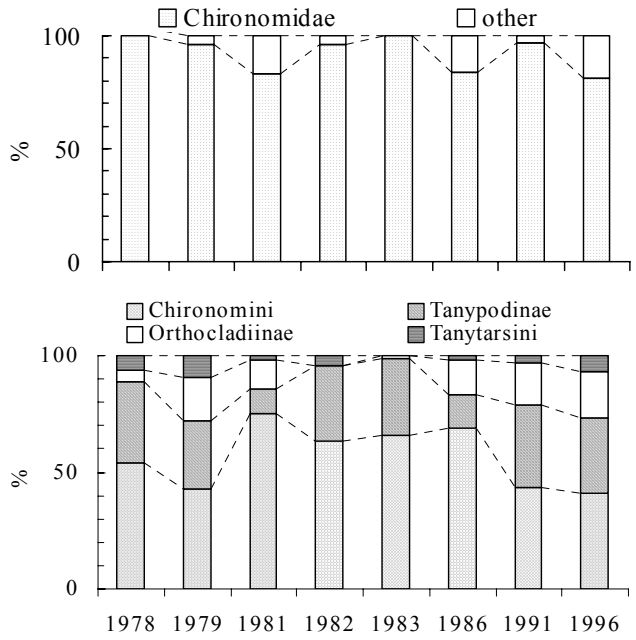

Fig. 6. Mean annual relative biomass of major taxonomic groups in the total zoobenthos and chironomids biomass.