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Long-term modification of Arctic lake ecosystems: Reference condition, degradation under toxic impacts and recovery (case study Imandra Lakes, Russia)

Tatyana I. Moiseenko[a,*], Andrey N. Sharov[b], Oksana I. Vandish[c], Lubov P. Kudryavtseva[c], Natalia A. Gashkina[a], Catherine Rose[d]

[a]*Water Problems Institute, Russian Academy of Sciences, Gubkina 3, GSP-1, Moscow 119991, Russia*
[b]*Institute of Water Problems of the North, Russian Academy of Sciences, Nevskogo, 50, Petrozavodsk 185003, Russia*
[c]*Institute of the North Industrial Ecology Problems, Kola Science Center, Russian Academy of Sciences, Fersmana St. 14a, 184200 Apatity, Russia*
[d]*Environmental Change Research Centre, University College London, Gower Street, London WC1E 6BT, UK*

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Abstract

In this study, published data on Lake Imandra, north-west Russia, have been synthesised to investigate trends in lake contamination and recovery due to changing inputs of heavy metals and nutrients over time. Records of water chemistry, phytoplankton, zooplankton and fish communities have been used to determine the status of aquatic ecosystem health in three distinct phases of Lake Imandra's recent history. Firstly, background (reference) conditions within the lake have been established to determine lake conditions prior to anthropogenic influences. Secondly, a period of ecosystem degradation due to anthropogenic inputs of toxic metals and nutrients has been described. Finally, evidence of lake recovery due to recent decreases of toxic metals and nutrients has been explored. Pollution of Lake Imandra began in the 1930s, reaching a peak in the 1980s. Increases in heavy metal and nutrient inputs transformed the typical Arctic ecosystem. During the contamination phase, there was a decrease in Arctic species and in biodiversity. During the last 10 years, pollution has decreased and the lake has been recolonised by Arctic water species. Ecosystem recovery is indicated by a change of predominant species, an increase in the individual mass of organisms and an increase in the biodiversity index of plankton communities. In accordance with Odum's ecosystem succession theory, this paper demonstrates that the ecosystem has transformed to a more stable condition with new defining parameters. This illustrates that the recovery of Arctic ecosystems towards pre-industrial reference conditions after a reduction in anthropogenic stresses occur, although a complete return to background conditions may not be achievable. Having determined the status of current ecosystem health within Lake Imandra, the effect of global warming on the recovery process is discussed. Climate warming in Arctic regions is likely to move the ecosystem towards a predominance of eurybiontic species in the community structure. These organisms have the ability to tolerate a wider range of

*Corresponding author. Tel.: +7 495 135 33 20; fax: +7 495 135 54 15.
E-mail address: tatyana@aqua.laser.ru (T.I. Moiseenko).

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environmental conditions than typical Arctic inhabitants and will gain advantages in development. This indicates that the full recovery of Arctic ecosystems in a warming climate may not be possible.

Keywords: Arctic; Aquatic ecosystem; Toxic impacts; Modification; Reference condition; Degradation; Recovery

Introduction

Understanding the impact of anthropogenic contamination on aquatic ecosystems, and also their subsequent recovery as a result of decreasing anthropogenic stress, is important for successful environmental management. The recovery of aquatic ecosystems due to decreasing anthropogenic inputs, including toxic pollutants, has been well-documented in the scientific literature (e.g. Gunn et al. 1995; Jeppesen et al. 2005; Cairns 2005; Harris et al. 2006; Hobbs 2007; Palmer et al. 2007). The impact of anthropogenic pollution on aquatic environments varies greatly across different climatic regions. Arctic ecosystems are particularly vulnerable due to cold water, simplified food webs, low biodiversity, rapid transfer of material through trophic levels, and the stenobiontic character of aquatic species. This can result in the rapid migration of pollutants throughout food webs causing severe damage to ecosystems. However, knowledge about the recovery of these ecosystems is limited and further information is required on whether the recovery to natural characteristics is possible, which reference conditions should be taken for the purposes of ecosystem recovery and whether climate change will affect the recovery process. The changes that are currently occurring in aquatic ecosystems often have analogues in the past that can be used to predict different scenarios of future change. Harris et al. (2006) emphasised the significance of studying recovery mechanisms in order to predict the ecosystem state.

This study of Lake Imandra provides a unique opportunity to explore the anthropogenic modification of an Arctic ecosystem. Lake Imandra is situated within the Arctic Circle in the Kola Peninsula, Russia. The lake has an area of 880 km^2 with a catchment area of 12,300 km^2, the maximum depth is 67 m and mean depth is of 13 m. The lake has a complex shoreline and consist of three main basins connected by narrow passages (Fig. 1). It has been subject to greater levels of pollution than many Arctic lakes. Industrial development of copper- and nickel-rich apatite–nephelinite and iron deposits in the catchment area of Lake Imandra began in the 1930s. Considerable industrial expansion in the early 1900s resulted in the building of large industrial enterprises in the lake catchment. Large amounts of pollutants entered the lake between 1940 and 1990; the catchment area was also was polluted by airborne contaminants. The main pollutants were heavy metals (predominantly nickel and copper), sulphates, chlorides and nutrients. The main pollution occurred in the northern part of the lake (Bol'shaya Imandra). Since 1990, as a result of the economic crisis in Russia, anthropogenic pressure on the lake has decreased. The recent recovery of the economy has occurred simultaneously with technological modernisation and tighter controls of pollutant emissions into the lake and the atmosphere.

The exploitation of mineral resources in Arctic regions has increased in recent years which makes the case of Lake Imandra important. It is a useful case study in environment management, particularly the avoidance of negative impacts of Arctic mineral resources exploitation.

This study aims to clarify the main changes in the lake's ecosystem over time (the change from background conditions through a period of degradation to a recent recovery) using retrospective analysis of ecosystem dynamics.

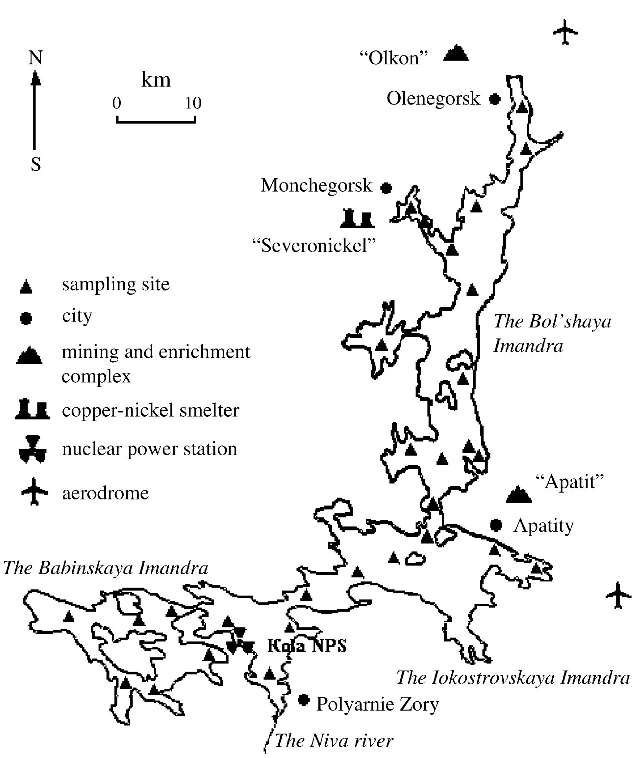

Fig. 1. A map of Lake Imandra showing the distribution of sampling sites, cities and industrial enterprises ('Olkon' complex specialises in iron ore, 'Apatit' complex specialises in apatite–nepheline ore).