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Relationships and bioaccumulation of chemical elements in the Baikal seal (*Phoca sibirica*)

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Biomagnification may be occurring in the fish–seal trophic link.

Abstract

Concentrations of Al, Ba, Cd, Cu, Fe, Mn, Mo, Si, Sr, Zn, Ca, K, Mg, Na and P in the livers of Baikal seal, plankton, zoobenthos, and fish, constituting the food sources for the seals, were determined by ICP-MS and ICP-AES. The accumulation of elements in the liver of seals, affected by internal and external (environmental) factors, was assessed by multidimensional (ANOVA, FA) and correlation analyses. FA has enabled identification of abiotic and biotic factors responsible for the accumulation of elements in the livers of Baikal seals. Significant influence of sex and development stage of the seals analysed on hepatic concentrations of some elements was found. The observed differences in element concentrations between pups, males and females could be attributable to the reproductive cycle of this species. ANOVA showed differences in concentrations of Fe, Zn, Cu and Cd in seals from the three separate basins of the lake. BMFs suggest biomagnification of Fe and Zn in the fish–seal trophic link.

Keywords: Chemical elements; Baikal seal; Biomagnification; Factor analysis

1. Introduction

Lake Baikal is the deepest (1642 m), volume-wise (23,615 km^3) and the largest body of fresh water in the world. A large, deep water in the south and central Baikal Basins formed during the Late Oligocene to Early Miocene (27–17 Ma) (Mats et al., 2000; INTAS Project 99-1669 Team, 2002). Known as 'the pearl of Siberia', it constitutes a unique ecosystem inhabited by numerous endemic species of fauna and flora. The only species of seal living exclusively in fresh waters, the Baikal seal (*Phoca sibirica*), is the final link in the Baikal pelagic food chain. Like the Caspian seal, the Baikal seal is one of the smallest of the true seals (Phocidae). The Baikal seal's principal food source consists of fish from the family Comephoridae, which is endemic to Baikal (Pastukhov, 1993; Petrov and Egorova, 1998).

The relatively straightforward trophic relationships in Baikal (Gurova and Pastukhov, 1974) make it fairly easy to follow the biogeochemical fate of elements in the lake. At present, the contamination of Lake Baikal, declared a UNESCO World Heritage Site in 1996, is of considerable significance. Industrial activities in the immediate vicinity of the lake have aroused suspicions of a link between the discharge of effluent and the

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distemper epidemic that afflicted the seals in 1987–1988 (Grachev et al., 1989). A variety of abiotic and biotic components of Baikal have been analysed for the content of elements, in particular those of confirmed toxicity (Vetrov and Kuznetsova, 1997; Grachev, 1999; Falkner et al., 1991, 1997; Grosheva et al., 2000; Anokhin and Izrael, 2000; Munawar et al., 2000).

Baikal Lake pollution is attributable to the abundant energy and mineral resources in the drainage area. Anthropogenic emission comes from the developing energy-consuming industries such as metallurgy, including non-ferrous metallurgy, mining, chemical, pulp and paper industries, timber and woodworking as well as the power and fuel industries. Typical pollution connected with such activities includes dust and soot, nitric and sulphur oxides and heavy metals.

Baikal Lake has been influenced by the following industrial and agricultural regions: Irkutsk-Cheremkhovo industrial zone, TPK (cities of Irkutsk, Shelekhov, Angarsk, Usol'e-Sibirskoe, Cheremkhovo and Zima), Selenga river drainage basin (industry of Ulan-Ude and other cities on Russia and Mongolia territories, agriculture), Baikalsk Pulp and Paper Mill, Baikal-Amur Railway zone, BAM, adjacent to the Baikal (Severobaikal'sk harbour and Nizhneangarsk city) and the Upper Angara river drainage basin and the Barguzin river drainage basin.

The huge amount of fuel burned, e.g. in the TPK industrial centre is associated with emission of a considerable amount of heavy metals into the atmosphere transported by the predominant northwesterly winds from the TPK area to Lake Baikal. Among many anthropogenic emitters, the Irkutskenergo Company alone burned 15.8 million tons of coal in 1979 emitting 216,000 tons of toxic gases and 156,100 tons of ash. In the Ulan-Ude industrial region (including Selengisk Pulp and Paper Mill) considerable amount of pollutants enters the Selenga River, the major tributary of Lake Baikal. In the 1980s, 264,000 tons of mineral substances, including 70,000 tons of sulphates, 4700 tons of hydrocarbons and 100 tons of phenols entered this river annually (Vetrov and Kuznetsova, 1997). Finally, it was estimated that of the total loads reaching Baikal, the Selenga carried 30–50% of P, 12–15% of Cd and 5–7% of Zn (Grosheva et al., 1998).

An important source of Lake Baikal pollution is the Baikalsk Pulp and Paper Plant (BPPP), situated directly on the Lake shore. It should be emphasized that 6876 tons of pollutants were emitted in 2003 from the BPPP to the atmosphere. In this region the amount of poorly treated waste water discharging directly into Baikal was estimated to be 46.5 million m^3 in 2002, including 0.110 million m^3 of untreated waste (Afanas'eva et al., 2004).

As far as the Baikal biota are concerned, heavy metals and other elements have been determined inter alia in the tissues and organs of Baikal seals. Most reports do not indicate elevated levels of toxic metals in the seals (Vetrov and Kuznetsova, 1997; Watanabe et al., 1996, 1998; Ikemoto et al., 2004; Beim et al., 2000), or in any other living organisms in the lake (Grosheva et al., 2000). Pb levels reported from sediment cores taken from the southern part of the lake were slightly higher than expected, unlike those of Cu and Zn, whose presence cannot be attributed to anthropogenic factors (Boyle et al., 1998). The 'scientific testing ground', which this lake has become, provides a unique opportunity to study biogeochemical phenomena in their 'original version', in contrast to other water bodies, such as the Baltic Sea, which are exposed to human factors to a much greater extent (Szefer, 2002).

The Baikal seal inhabits the entire lake. Seasonal migrations are undertaken primarily in response to changing hydrological conditions, such as the appearance of surface ice, and also to the availability of food and the threat of predation. Its numbers (the basic stock, not including pups) were estimated at 70,000 in 1972–1975, 67,000 in 1980 and 62,000 in 1985 (Pastukhov, 1993). According to the latest figures, the total Baikal seal population is estimated at around 82,000 (Petrov et al., 1997).

The aim of the present work was to assess the relationships between chemical elements and their bioaccumulation and biomagnification in the Baikal seal, bearing in mind the possible occurrence in the Baikal ecosystem of unique bioaccumulation patterns, different from those recorded in sea waters which may be subject to certain elements like Rb (Ikemoto et al., 2004). The present study was also projected to determine the status of Lake Baikal contamination by trace elements as well as to examine using a chemometric approach the possible age trends and sexual differences in their bioaccumulation in the Baikal seals.

2. Materials and methods

2.1. Samples

Liver samples ($n=27$) from Baikal seals (*Phoca sibirica*) were taken between 7 and 22 April 2001 from animals found dead ($n=11$) or obtained from hunters during the official cull ($n=16$) in the same period of time. The age of adult seals was determined from an analysis of the growth of the dentinal and cemental growth layers in the canine teeth. Samples of fish (*Comephorus dybowski*, *Comephorus baicalensis*, *Cottocomephorus inermis*, *Cottocomephorus grewingki*), plankton, and zoobenthos species (*Acanthogammarus godlewski*) were obtained with the use of suitable nets. Fish were homogenised on the whole except two largest specimens from which liver was taken and analysed for