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Modelling the properties and stability of meromixis induced by saline mine waters in two boreal lakes

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Mine waters are a significant point source stressor for aquatic environments. Acid mine drainage has long been considered a big environmental issue, but recent studies suggest that the salinity of mine waters may also be harmful particularly to small, dimictic lakes which are abundant in the boreal region. The denser saline mine waters may cause a shift in the mixing regime of a lake, leading to a permanent stratification of the water column, i.e. meromixis. As the demand for raw materials increases, mining companies, policy makers, and environmental regulators need to be more aware of these harmful effects of saline mine waters. In this study, two lakes receiving drainage waters from closed copper-nickel mines are investigated. Lake Valkeinen and Lake Sortavalanjärvi are situated in Eastern Finland near the mines Kotalahti (active 1959–1987) and Laukunkangas (active 1986–1994), respectively. The waters from the mines have been managed according to the permit conditions and in the case of Lake Valkeinen are primarily discharged elsewhere. Nevertheless, the mixing regimes of the lakes have seemingly shifted to meromictic.

To study the present conditions of the lakes, water samples and in-situ water column measurements were collected seasonally. Lake Valkeinen was sampled in 2017 and 2018, and Lake Sortavalanjärvi in 2018. Inflowing and outflowing streams were also sampled at both locations. Element concentrations and other chemical properties were analysed from the water samples. The stability of meromixis under varying conditions in the lakes was modelled with MATLAB-based open source model code MyLake that was modified to account for the changing density caused by increased salinity. This was done using conductivity as an explaining quantity.

The results suggest that the lakes are permanently stratified at present with a chemocline separating the circulating, well-oxygenated upper water (mixolimnion) from the non-circulating, hypoxic bottom water (monimolimnion). The maximum depth of both lakes is ca. 16 m and the chemocline is situated at the depth of 8-10 m with some seasonal shifting in both lakes. In Lake Valkeinen, electrical conductivity (EC) was ca. 500 mS m^{-1} in the mixolimnion on all occasions and ca. 600 mS m^{-1} or more in the monimolimnion. In Lake Sortavalanjärvi, EC was ca. 600 mS m^{-1} in the mixolimnion and ca. 1200 mS m^{-1} in the monimolimnion. pH was circumneutral, with a slightly lower pH in the monimolimnia of the lakes on most occasions. Main anions were S and SO_4 in both

lakes, while main cations were Ca, Mg, Na, and K. SO_4 concentrations were 250-280 mg l^{-1} in the deepest part of Lake Valkeinen and 520-640 mg l^{-1} in Lake Sortavalanjärvi. The results from MyLake scenarios suggest that the meromixis would be sustained even if external load ceased completely and a change in prevailing wind conditions is the only factor that could significantly alter the situation. The elevated concentrations of the conservative elements inflowing from the mine area coupled with a favourable position of the lakes in relation to main wind directions seem to sustain the meromictic conditions in these lakes.