Nutrient turnover at the hypoxic boundary: flux measurements and model representation for the bottom water environment of the Gulf of Riga, Baltic Sea*

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Abstract

Experimental studies of intact sediment cores from the Gulf of Riga, Baltic Sea, were conducted to estimate the response of sediment nutrient fluxes to various near-bottom water oxygen conditions. The experiment was performed in the laboratory using a batch-mode assay type system on the sediment cores held at 4°C and oxygen concentrations maintained at 1, 2, 3, 4 and 5 mg l^{-1}. The results from the experiment were subsequently used to optimise the fit of the sediment denitrification sub-model of the Gulf of Riga basin. Sediment-water fluxes of phosphate were low and directed out of the sediments under all treatments, demonstrating a general decreasing tendency with increasing near-bottom water oxygen concentration. The sediment-water fluxes of ammonium and nitrate + nitrite demonstrated opposing trends: ammonium fluxes decreased whereas nitrate + nitrite fluxes increased with rising near-bottom water oxygen concentration. The modelled fluxes agreed well with the measured ones, with correlation coefficients of 0.75, 0.63 and 0.88 for ammonium, nitrate + nitrite and phosphate fluxes respectively. The denitrification rate in sediments was simulated at oxygen concentrations from -2 to 10 mg l^{-1}. At oxygen concentrations < 2 mg l^{-1} the modelled denitrification was sustained by nitrate transport from water overlying the sediments. With increasing oxygen concentrations the simulated denitrification switched from the process fuelled by nitrates originating from the overlying water (D_w) to one sustained by nitrates originating from the coupled sedimentary nitrification – denitrification (D_n). D_n reached its maximum at an oxygen concentration of 5 mg l^{-1}.

1. Introduction

Industrial and agricultural development has resulted in enhanced loads of nitrogen and phosphorus over the last 100 years, causing marine ecosystems to deteriorate (e.g. Nixon et al. 1995). Semi-enclosed marine regions, such as the Baltic Sea (e.g. Witek et al. 2003), and its sub-areas with large terrestrial loads, such as the Gulf of Riga (e.g. Yurkovskis et al. 1993), are particularly impacted by elevated nutrient levels. Most of the increase in riverine nutrient loads to the Baltic Sea occurred before the 1970s (Stålnacke et al. 1999), although annual increases of approximately 5% and 2–3% for nitrate and phosphate, respectively, have been estimated for the period 1970–1990 (Rahm & Danielson 2001). Similarly, the negative effects of anthropogenic nutrient loading from urban and agricultural sources were evident already in the 1950s in the Gulf of Riga (Ojaveer 1995). Thereafter, the deterioration of the Gulf of Riga environment accelerated in the 1970s and 1980s (Ojaveer 1995), reaching a peak in 1990 (HELCOM 2010). Since then, nitrogen inputs have decreased but phosphorus has continued to increase (HELCOM 2013).

One of the most conspicuous and environmentally significant effects of environmental deterioration is the establishment of hypoxia and anoxia in