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Effects of sediment and nutrient enrichment on water quality in the Archipelago Sea, northern Baltic: An enclosure experiment in shallow water

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Abstract

The effects of bottom sediment and nutrient enrichment on water quality were studied in an enclosure experiment in the Archipelago Sea, northern Baltic. The three-week experiment was conducted in a small and shallow bay, where the organic content of the sediment is low. The enclosures were large (diameter 3.6 m, depth 3.5 m), and reached from the surface to the bottom. Some of the enclosures included the natural sediment, some had a plastic bottom without contact with the sediment. Concentrations of nutrients and chlorophyll *a* and physical variables in the water column, concentrations of inorganic nutrients in the pore water of the sediment, and numbers and biomasses of the benthic macrofauna were measured. Both the presence of sediment and nutrient enrichment significantly increased the concentrations of total nitrogen, total phosphorus and chlorophyll *a* in the water column. The concentration of chlorophyll *a* doubled in the sediment-bottomed enclosures without nutrient enrichment; the increase was similar to that in the plastic-bottomed enclosures with nutrient enrichment (7.2 μM NH_4^+ and 0.46 μM PO_4^{3-} during the three-week study). The concentration of silica doubled or tripled in the sediment-bottomed enclosures. No shortage of oxygen was found in the water column during the experiment. The results show that sediment with a low content of organic matter may serve as an important source of nutrients in shallow and littoral oxic waters and may be important in sustaining their eutrophic state during the productive season. It is suggested that an important part of the nutrients released from this erosion bottom had originated from the surface layer of the sediment, which had been sedimented and transported to the area quite recently. The results indicate that it is important to include sediment in mesocosm studies dealing with nutrient dynamics, especially in shallow waters.

Keywords: sediment; benthic fluxes; nitrogen; phosphorus; eutrophication; mesocosms

1. Introduction

Sediment plays an important role in nutrient dynamics in lake and marine ecosystems (e.g. Krom and Berner, 1981; Boström et al., 1982; Fisher et al., 1982; Blackburn, 1986; Sundby et al., 1992). Sediment is important in relatively shallow environments, such as continental shelves, estuaries and other coastal areas, where the sedimentation rate is high (Jørgensen, 1983).

Nutrients occur in sediments in different forms. In part the nutrients deposited on the bottom in particulate form are precipitated within the sediment, but part may be regenerated and released back into the water column (Ruttenberg and Berner, 1993). In oxidizing surface

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sediments the most easily regenerated forms of nutrients are those bound to organic matter, from which they are released via decomposition. Phosphorus (P) adsorbed on metal oxides, especially iron, is another important form of regenerating P, which is released in anoxic conditions via reduction of the metal oxides (Krom and Berner, 1981; Rozan et al., 2002). Regenerating N also occurs in the sediment as exchangeable ammonium, which is adsorbed on sediment particles (Blackburn and Henriksen, 1983; Mackin and Aller, 1984). From these pools the nutrients may be released into the pore water and further back into the water column, thus becoming available to primary producers.

Nutrients may be released from the bottom below the photic zone (e.g. Rowe et al., 1975; Koop et al., 1990; Sundby et al., 1992) as well as from shallower areas, where the productive layer reaches the bottom (Klump and Martens, 1981; Fisher et al., 1982; Rozan et al., 2002). In deeper areas the main release mechanisms are molecular diffusion within the sediment and further through the sediment–water interface and bioturbation by sediment-dwelling benthic fauna (McCaffrey et al., 1980; Aller, 1982; Enell and Löfgren, 1988; Hansen and Kristensen, 1997). In shallow waters other factors, such as wind-induced turbulent currents and resuspension, may also be important in nutrient release (Boström et al., 1988; Weyhenmeyer, 1998). Furthermore, in shallow environments the nutrients are more readily available to primary producers than on deeper bottoms.

Estimates of benthic nutrient fluxes are usually based on diffusion rate calculations (Enell and Löfgren, 1988) or on direct measurement of the fluxes either with benthic chambers in situ or with intact sediment cores in the laboratory (Rutgers van der Loeff et al., 1984; Sundby et al., 1992). An alternative way of estimating the effect of sediment on the water column is the use of experimental mesocosms which contain the sediment. Most such studies have been carried out with grafted sediments in laboratory conditions or in land-based mesocosms (e.g. Pilson et al., 1980; Kelly and Nixon, 1984; Sullivan et al., 1991; Rhew et al., 1999). Enclosure experiments with natural intact sediments have usually been conducted in lakes (Levine and Schindler, 1992; Reynolds, 1996; Cottingham et al., 1997), but seldom in marine conditions (Smetacek et al., 1982; Riemann et al., 1988). The comparison of enclosures with and without sediment offers a way not only to estimate the amount of released nutrients, but also to directly measure the ecological effects of the sediment on the water column. However, only few such studies have been conducted (but see Riemann et al., 1988; Beklioglu and Moss, 1996; Schindler, 1998).

To assess nutrient release from sediment and its ecological effects under maximally natural conditions, an experiment was carried out in large enclosures with or without natural sediment as a bottom. The aim was in particular at estimating the effects of sediment on parameters indicating eutrophication and at comparing the effects of sediment to those of known nutrient additions to the water. The study was conducted in the Archipelago Sea, northern Baltic, in a shallow area on an erosion bottom where the organic content of the sediment is low.

2. Materials and methods

2.1. The Archipelago Sea and the study site

The study area is situated in the brackish Archipelago Sea off the southwest coast of Finland (Fig. 1). The sea area is shallow, with a mean depth of only 23 m. The Archipelago Sea, like the whole Baltic, has eutrophied during recent decades (Bonsdorff et al., 1997; Hänninen et al., 2000). The main external nutrient sources are diffuse loading, fish farming, aerial deposition (especially of nitrogen), municipal wastewaters, and background loading from the Baltic Proper and the Gulf of Finland (Helminen et al., 1998). It has been suggested that nutrient regeneration from the sediment (=internal loading) also contributes to the eutrophic state of the Archipelago Sea, but its role has not been directly measured or experimentally studied.

The experiment was carried out close to the island of Seili (60°15′N, 21°58′E) in the mesotrophic middle part of the Archipelago Sea, in the summer of 2001 (Fig. 1). In the study area the mean concentrations in the surface water in July–August are 25 μM, 0.65 μM and 3 $\mu g\,l^{-1}$ for total N, total P and chlorophyll *a*, respectively. Tides are insignificant and salinity is about 6 in practical salinity units.

The experimental site was a small shallow bay (depth < 5 m) where the euphotic layer reaches the bottom. The bay is open to eastern winds, and a fairway at about 3–4 km distance produces regular deep and smooth waves. The bottom sediment was grayish Ancylus clay (Rantataro, 1999), i.e. of postglacial origin, with a low content of organic matter. There was only a thin (<5 mm) unconsolidated layer (“fluffy layer”) at the surface of the sediment and the depth of whole brown layer, indicating presence of Fe (III) oxides, did not exceed 8–10 mm. The mean concentrations in the upper 0–3 cm have been measured at 285 $\mu mol\,g^{-1}$ DW (dry weight) for total N, 26 $\mu mol\,g^{-1}$ DW for total P and 569 $\mu mol\,g^{-1}$ DW for total C (Gran, unpubl.). C/N ratio (by mass) was 2.0. Loss of ignition (LOI) was 3.7% DW, indicating low content of organic matter. The LOI value is much lower than values e.g. in certain accumulation bottoms in the Archipelago Sea (8–11% DW; Gran, unpubl.) or in the eastern Gulf of Finland (9–25% DW; Lehtoranta and Pitkänen, 2003).