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Release of organic P forms from lake sediments

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ABSTRACT

The effects of different physical and chemical conditions on the decomposition and release of organic and inorganic P compound groups from the sediment of Lake Erken were investigated in a series of laboratory experiments. Conditions investigated were temperature, oxygen level, and the effects of additions of carbon substrate (glucose) and poison (formalin). The effects on the P compound groups were determined by measurements with ^{31}P NMR before and after the experiments, as well as analysis of P in effluent water throughout the experiment. Phosphate analysis of the effluent water showed that oxygen level was the most influential in terms of release rates, with the sediments under anoxic conditions generally releasing more phosphate than the other treatments. ^{31}P NMR showed that the various treatments did influence the P compound group composition of the sediment. In particular, the addition of glucose led to a decrease in orthophosphate and polyphosphate while the addition of formalin led to a decrease in phosphorus lipids, DNA-phosphate and polyphosphate. Oxic conditions resulted in an increase in polyphosphates, and anoxic conditions in a decrease in these. Temperature did not seem to affect the composition significantly.

1. Introduction

The importance of phosphorus (P) as a nutrient in aquatic environments is well understood (e.g. Schindler, 1977; Wild, 1988; Hecky, 1998), and recent years have highlighted organic P compounds as an important part of the active P pool (e.g. Hupfer et al., 1995; Reitzel et al., 2006a; Ahlgren et al., 2005). Organic P compounds, which earlier were regarded as part of the refractory P pool, are now known to contain many labile species which may play an important role in the aquatic P cycling (e.g. Turner et al., 2005; Reitzel et al., 2007).

In most aquatic environments, the sediment plays an important role in P cycling as it is able to store a large part of the P that settles out from the water body, either temporary or permanently. Phosphorus stored temporary will eventually be recycled to the water column. In areas where the external P input has been significant and the temporary storage of sediment P is large, sediment P recycled may under certain conditions be larger than external input from e.g. rivers (Ahlgren et al., 2006). Since recent studies have demonstrated that organic P compounds play an important role in the process of sustaining eutrophication (Ahlgren et al., 2005, 2006), more detailed knowledge on factors controlling the release of sediment P is of great importance. Several studies concerning inorganic P have been presented (e.g. Boström et al., 1982; Jensen and Andersen, 1992; Rydin, 2000; Søndergaard et al.,

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2003; Hansen et al., 2003; Ahlgren et al., 2005; Hupfer and Lewandowski, 2005) but investigations concerning specific organic P compounds, their diagenesis and potential mobility in aquatic sediments are absent as far as we know. It is thus of great importance to investigate what factors influence organic sediment P turnover. These mechanisms however, are difficult to monitor under natural conditions and more detailed answers may be available from controlled laboratory experiments. Laboratory studies investigating the release of P from the sediment under various conditions have identified the amount of potentially mobile P, but not in what form it is released (e.g. Rydin, 2000; Hansen et al., 2003). The phosphorus nuclear magnetic resonance spectroscopy (^{31}P NMR) technique has the potential to distinguish between different organic P compound groups (e.g. Newman and Tate, 1980; Turner et al., 2003) and thereby provide information on which species of P are lost from the sediment under the investigated conditions.

The overall goal of this study is to increase our understanding of which organic P forms can be considered to be stored temporary or permanently in the sediment under various conditions, by performing controlled manipulated P release experiments. Using the ^{31}P NMR technique, we primarily aim at identifying the mobility of different P compounds at different oxygen levels, as redox conditions are known to be a major driving force behind P related processes within sediments, including internal loading. In addition to this, the impact of the microbial community was investigated, since micro organism activity is likely to have as great an impact on P turnover as redox conditions. These processes are indeed closely intertwined, and for example bacteria release P under reducing conditions, a process that may constitute a large part of P release during anoxic conditions (e.g. Gachter et al., 1988; Gächter and Meyer, 1993). Furthermore, the fact that bacterium are dependent on electron acceptors to utilize and decompose organic matter means that the redox potential will play a central role in the sediment, reflecting the activity of microorganisms as they reduce the electron acceptors (Golterman, 2004). Temperature is another vital parameter for biological processes in the sediment, which is proven by the seasonal variations in internal loading (e.g. Jensen and Andersen, 1992; Søndergaard et al., 1999). This is most likely due to increased mineralization of organic matter by microorganisms as the temperature increases. Apart from stimulating mineralization of organic P compounds, a rise in temperature also increases the release of inorganic phosphate from sediment (e.g. Boström et al., 1982).

We simulated these scenarios by exposing the sediment to different levels of oxygen, different temperatures, and different levels of microbial activity by adding glucose (high activity level) or formalin (low level). These additions were made to investigate the impact of the microbial community, and specifically whether it is possible to distinguish between microbial and chemical decomposition of the various P species in the sediment, since the addition of glucose should act as substrate for the microbial communities in the sediment, accelerating the microbial decomposition of P species. This could on the one hand lead to an increased mineralization and release of P from the sediment or on the other hand lead to an increased uptake of P and hence, a lower release of P if the microbial community is P limited. In contrast, the addition of formalin was used to terminate all microbial activity in the sediment, releasing microbes and thereby microbial P, thus making chemical decomposition the dominant process in these treatments. Additions of glucose and formalin were made at both high and low oxygen levels to investigate the redox potentials influence on the microbial community.

2. Materials and methods

2.1. *Sampling and study site*

In this study, sediment from the moderately eutrophic Lake Erken (Sweden) was used to follow potential diagenetic changes under laboratory conditions. The average total P concentration in the lake water is 27 μg L^{-1} and the lake has a surface area of 24 km^2, and mean and maximum depths are 9 and 21 m, respectively. The drainage area (137 km^2) is mostly forested and consists of nutrient-rich glacial and post-glacial clay deposits. During summer stratification, bottom water occasionally becomes anoxic. The lake has been studied extensively, and Rydin (2000) argue that the lake has been in a stable trophic state since observations began in 1930.

Twelve sediment cores were collected with a gravity core sampler (Willner sampler) at a depth of 16 m within an accumulation bottom area (50 m^2). The 0–1 cm layer of the cores was collected, pooled, and homogenized to obtain a representative sample of sufficient size for the experiment. The sediment in this layer had a total P concentration of 2.0 mg g^{-1} dry weight, water content of 93%, organic matter content 200 mg g^{-1} dry weight and total Fe content was 24 mg g^{-1} dry weight. pH in the benthic water varied between 7 and 7.5.

2.2. *Laboratory set-up*

The pooled sediment sample was divided into 20 sub-samples of 15 g (wet sediment) which each was encapsulated into water filled sediment chambers (Fig. 1) similar to the one used in Rydin (2000). Through these chambers water with different characteristics was pumped upwards through the sediment at a rate of 0.3 L day^{-1}. The slow flow rate and chamber set up with frits at the inflow ensured minimum physical impact on the sediment, without channelling or compaction. The sediment was treated with different conditions i.e. oxic–anoxic water, different temperatures (4 °C and 20 °C) as well as oxic and anoxic water with addition of glucose (1% weight/weight (w/w)) and formalin (3.7% w/w) at 20 °C. Temperatures were chosen to simulate potential maximum high and low conditions at the sediment surface. Oxygen conditions were monitored through redox potential measurements and corrected by additions of a reducing agent (dithionite). Oxic conditions were considered as when the inflowing water was in equilibrium with the surrounding air, and anoxic conditions when the redox potential was below 0 mV. To ensure correct and consistent oxygen levels, pH and concentrations of additives throughout the experiment, new aliquots of the various inflow water solutions were mixed twice a day. The pH value was adjusted to 7 in all solutions. Treatments were made in triplicates, except for treatments with addition of glucose and formalin, which due to space restrictions were made in duplicates. From each of