

Interactive comment on “Phosphorus recycling in sediments of the Central Baltic Sea” by L. Viktorsson et al.

L. Viktorsson et al.

lenav@gvc.gu.se

Received and published: 1 February 2013

In the general comments on the manuscript the reviewer points out that the conclusions would have been significantly strengthened if we could also show Fe and oxygen fluxes. Regarding Fe fluxes we unfortunately have no such data. Oxygen fluxes are available from all incubations where there was oxygen in the bottom water. However, we have chosen to use DIC flux as a measure of organic carbon oxidation rate rather than oxygen uptake of several reasons. DIC is the end product of organic carbon degradation and the DIC flux a better proxy for organic carbon degradation than oxygen consumption. This is mainly because oxygen is only one of many electron acceptors, and oxygen is used in oxidation of both reduced inorganic substances and organic carbon. Since the production of reduced inorganic substances during anoxic organic matter

C7877

degradation and the reoxidation of them with oxygen do not take place simultaneously, oxygen uptake is not a good measure of benthic respiration in sediments where anoxic organic matter degradation pathways take place (like in the Baltic) (see e.g. Anderson et al., 1986; reference given in the manuscript). Another very important reason we used DIC flux instead of oxygen uptake is that the latter cannot be measured in water where oxygen does not exist; this was the case at roughly half of the stations in our study. The reviewer also asks for organic carbon and organic phosphorus data, we assume this refers to sediment data. We do have sediment organic carbon data and they are (and were at submission) presented as organic carbon inventory in relation to DIP flux in Figure 9. After some consideration we have also chosen to include the small set of dissolved organic phosphorus (DOP) fluxes, which we have. They are from three chamber incubations at station H (44 m depth) in August 2010. These results show that also when the DIP flux is zero there can be a DOP efflux at oxic bottoms. Regarding sediment organic P data we unfortunately have only quantified total P concentrations.

p. 463, 11:

The referee has rightfully commented on the fact that the data we have presented cannot be used to elucidate the importance of bottom types for DIP fluxes. Thus in the revised manuscript, we no longer state that we aim to describe the effects of various bottom types on benthic DIP fluxes. As noted by the referee, this is because anoxic bottoms are generally found in the accumulation areas and the oxic bottoms are found in erosion and transportation areas. It cannot be out ruled that the bottom type influences the exchange of DIP across the sediment–water interface. However, the bottom water oxygen condition is most likely a much more important factor. For example, Viktorsson et al. (2012) (reference given in the manuscript) showed that the DIP efflux from an accumulation bottom at about 90 m depth in the westernmost Gulf of Finland visited during three consecutive years was drastically decreased the second year when the bottom water had been naturally oxygenated, compared to the first and third year when oxygen was depleted from the bottom water. Therefore, we argue that the areal

C7878

extrapolation of our results based on bottom water oxygen conditions is sound and the best option given the data at hand. It can also be noted that the group 3 sediments (anoxic accumulation bottoms) influence our estimate of the integrated internal DIP load in the Baltic proper far more than the group 1 and 2 sediments (oxic and oxic-anoxic erosion/transportation bottom). An extrapolation based on bottom types would therefore give a very similar result. In that sense, to reach the main aim of the present study (i.e., to quantify the present and past state of internal DIP loading in the Baltic proper) we do not need detailed understanding of in what way the bottom type may influence sedimentary DIP dynamics.

Benthic DIP fluxes in coastal, shallow areas may certainly show significant seasonal variability. Lowest DIP retention in the sediment generally occurs in such areas when the near bottom water is relatively warm and has a relatively low oxygen concentration during mid- to late summer (Jensen et al. 1995; Lehtoranta 2003, reference given in the manuscript). Temporal variability of DIP fluxes from sediments at deeper sites in the open Baltic proper, where these variables are more or less constant (as at many sites in the present study), is very poorly constrained and we choose to conduct our measurements during a restricted part of the year (August-September) for all these cruises, since our aim was not to study seasonal variability. As referee 1 point out, we argue, based on the strong correlation between DIP and DIC fluxes from permanently anoxic (group 1) sediments, that these DIP fluxes are mainly driven by the depositional flux of organic matter to the seafloor and the subsequent degradation of this material. Variation in the deposition flux of organic matter should therefore theoretically result in variation in the benthic DIP efflux. Long-term sediment trap data from the central Gotland basin indicate that our measurement campaigns coincide with relatively intense sedimentation rates (Struck et al. 2004; Pollehne 2005; Leipe et al. 2008). We will address this in the revised manuscript and acknowledge that our extrapolation therefore may be an upper estimate of the P regeneration. However, we will also argue that there is an important dampening of the variability of process rates when the process “passes through” the sediment. Hence, the variability of the vertical POC flux to the sea-floor is

C7879

much larger than the variability of the benthic DIP flux, partly because diffusion is slow; there is a time lag for bacteria to react to input of new organic matter; and the input flux is often (especially on oxic bottoms with fauna) mixed down into the sediment.

p. 464, 11:

The correct term is transportation bottoms and this will be up-dated in the manuscript. The difference between an erosion bottom and a transportation bottoms is that on the transportation bottoms the net effect of sediment erosion/accumulation over a longer time scale (months-years) is close to zero. This means that sediment is eroded from the site during some time and accumulated during others, but over a long term the sediment accumulation rate is approximately zero (Jonsson et al. 1990, reference given in the manuscript).

p. 464, 26:

We have realized that the definition of the group two is somewhat un-precise. We will be more precise on this point in the revised manuscript. With this group we mean to include bottoms in the depth range between ca 75-90 m where the bottom water oscillates between oxic and anoxic conditions due to vertical movements of the halocline and the closely associated oxycline. The reason we have made this division is because the oxygen history of the bottom is important. Unlike group 1 and 3 sediments which can be assumed to have been anoxic/oxic for a long time (years) before sampling, group 2 sediments may likely have experienced variable near bottom water oxygen conditions in the recent past. For example, if a flux measurement is conducted at a presently anoxic bottom that recently experienced oxic conditions the flux should be influenced by the release of DIP from temporary sinks (e.g. Fe, bacteria), which were formed during previously oxic conditions. Conversely, a similar non-steady state DIP flux can occur during a short-term transition from anoxic to oxic bottom water conditions.

p. 468, 21:

C7880

All reviewers have commented on the TP profiles and we agree that they should, and will, be further analyzed/explained in the manuscript. Regarding this particular comment our conclusion is that the changes in TP profiles on station A and B (2008) is due to a combination of Fe(III)-P adsorption/coprecipitation near the sediment–water interface and a higher TP content in the post-glacial clay compared to more recently deposited sediment above the clay. The decrease from the surface to 6 cm depth is due to Fe(III)-P adsorption/coprecipitation in the surficial sediment, which is lost with increasing sediment depth and more reducing conditions. The increase below 6 cm depth is due to higher TP content in the post-glacial clay than in the more recently deposited sediment.

p. 471, 20:

We arrived at a potential scavenging of 5-10% of pore water DIP, assuming that each dissolved Fe in the pore water in the upper 3 cm of sediment adsorbs 0.5 DIP molecules upon a potential oxygenation event of the deep basin. For further explanations on this, please see our response to the comments from Jilbert T. (referee 2).

p. 475, 30:

The sentence will be rephrased as suggested.

p. 476, 4.9:

As noted by the referee we are referring to enhanced organic P regeneration in relation to organic C regeneration in sediments underlying anoxic bottom water. The referee feels that the arguments are not clearly presented and that the following sentence does not support the argument, “One mechanistic explanation which has been proposed is that phosphatases, enzymes which cleave off phosphate groups from organic matter, are used by C-limited bacteria to increase bioavailability of the organic matter C moiety (Steenbergh et al 2011)”. We agree that this sentence should, and will, be re-written to clearer explain how the findings of Steenbergh et al. (2011) (reference given in

C7881

the manuscript) supports preferential organic P regeneration in relation to organic C regeneration as found in our study.

We find the suggestion of switching section 4.4 and 4.5 appropriate as the present 4.4 represents the main findings of the paper.

Table 1:

Porosity is the volume percent of water in the sediment and water content is the mass percent of water in the sediment. As bottom types are defined from water content (Håkanson and Jansson 2002, reference given in the manuscript), we found that this was the most appropriate variable to present, and porosity is not necessary. Also, adding porosity to this busy table already full with information is not preferable.

BW (bottom water) will be defined in header.

Fig. 6:

Two panels with the titles “. . . 1st incubation” and “. . . 2nd incubation” show less than 9 points because two incubations were performed during the same deployment. This was achieved by opening the lid and ventilating the chamber after about 20 hours of incubation. During this 1st incubation 4 syringes were triggered. After this, another twenty-hour incubation was started and the remaining 5 syringes were triggered during this 2nd incubation.

Fig. 7:

Caption updated according to suggestion

Linguistic comment:

We agree on this and “on bottom” will be changed to “at bottom” in a revised version of the manuscript.

References not included in manuscript

C7882

Jensen, H. S., Mortensen, P. B., Andersen, F. O., Rasmussen, E., and Jensen, A.: Phosphorus Cycling in a Coastal Marine Sediment, Aarhus Bay, Denmark, *Limnol Oceanogr*, 40, 908-917, 1995.

Leipe, T., Harff, J., Meyer, M., Hille, S., Pollehne, F., Schneider, R., Kowalski, N., and Brügmann, L.: Sedimentary Records of Environmental Changes and Anthropogenic Impacts during the Past Decades, in: *State and Evolution of the Baltic Sea, 1952–2005*, John Wiley & Sons, Inc., 395-439, 2008.

Pollehne F (2005) Sedimentation of particulate organic matter in the central Baltic basin. *Baltic Sea environment fact sheets, HELCOM Indicator Fact Sheets 2005*. Online. [130128], http://www.helcom.fi/environment2/ifs/en_GB/cover/.

Struck, U., Pollehne, F., Bauerfeind, E., and v. Bodungen, B.: Sources of nitrogen for the vertical particle flux in the Gotland Sea (Baltic Proper) – results from sediment trap studies, *J Marine Syst*, 45, 91-101, <http://dx.doi.org/10.1016/j.jmarsys.2003.11.012>, 2004.

Interactive comment on *Biogeosciences Discuss.*, 9, 15459, 2012.