Biogeosciences Discuss., 7, C1308–C1312, 2010
www.biogeosciences-discuss.net/7/C1308/2010/

Biogeosciences
Discussions

Interactive comment on "Hypoxia and cyanobacterial blooms are not natural features of the Baltic Sea" *by* L. Zillén and D. J. Conley

L. Zillén and D. J. Conley

lovisa.zillen@geol.lu.se

Received and published: 8 June 2010

General comments:

Both physical (climate) and anthropogenic forcing (eutrophication) affect the size of the hypoxic zone in the Baltic Sea. Climate forcing by changes in saltwater inflows, freshwater variability and wind mixing, which all have an effect on the stratification of the water column and the ventilation of the deep waters in the Baltic Sea. Anthropogenic forcing, which during the last approximately 50 years is believed to have been the most dominate, by increasing the nutrient availability and therefore the primary production and oxygen consumption within the basin. The question is, when did humans begin to affect the environment in the Baltic Sea? As stated in the manuscript and in Zillén et al. (2008) we know from various paleoenvironmental studies of lakes in Europe including

lakes in countries in the Baltic Sea watershed, such as Sweden and Denmark, that lakes have been culturally enriched in nutrients (especially P) since Medieval time. It has accordingly been shown that eutrophication of Earth systems started much earlier than after the introduction of industrial fertilizers (e.g. Bradshaw et al. 2005; Renberg et al. 2001) even though it has accelerated after World War II. This has also been shown in several classic papers by estuarine scientists that have examined how nutrient budgets have changed with anthropogenic forcing (Boynton et al. 1995; Billen and Garnier 1997; Nixon 1997; Conley 1999). How could these systems (freshwater) in the Baltic Sea watershed have been affected by land-use changes and not the Sea itself? If nutrient inputs to the Baltic Sea have increased since Medieval time (as we demonstrate) hypoxia on pre-historical and historical time-scales cannot be considered to be fully natural. We also know that hypoxia in the Baltic Sea increases the internal P-load, which in turn sustains and amplifies eutrophication and the expansion of hypoxia (Vathera et al. 2007). Increases in N-availability enhances the spring bloom of phytoplankton, which in turn initiates sea-floor hypoxia and subsequent P-release from the sediment, causing low N/P ratios and blooms of cyanobacteria during summer. The Baltic Sea is thus sensitive to changes in both N and P inputs (Conley et al. 2009). We hypothesize that a rapid release of nutrients from the land during the Medieval expansion triggered hypoxia in the Baltic Sea - and once established - it increased the internal P-load and blooms of cyanobacteria. Hypoxia during the Medieval time period could thus be an ancient analogue to the modern situation, where rapid increases in nutrient loads has resulted in wide spread bottom water oxygen deficiency. In the manuscript, we do not neglect (even though we will put more emphasis on this in the revised manuscript) the effect of climate on hypoxia in the Baltic Sea. Instead we explore the role of long-term human impact as an additional trigger of hypoxia. Would it be correct to neglect such impacts, especially since numerous terrestrial palaeoecological and palaeoenvironmental studies demonstrate that they exist? The greatest concern of referee 2 is the estimates of past nutrient loads to the Baltic Sea and the bioavailabilty of the nutrients. We agree with the referee that it is difficult to estimate past nutrient loads, but the aim of this manuscript is to show that increases in nutrients took place - and not to provide a precise estimate of the loading. The estimates in the manuscript are only the expected losses of organic N due to plowing new land. They don't include P and C and supplementary nutrient losses from deforestation and continuous manuring of fields. Also, we do not know how rapid these nutrient losses may have occurred, which means we do not know the rate of change. In addition, we will exclude some of those estimates and put more effort in proposing what could be done in future investigations to provide more accurate estimates in order to reveal the relative importance of climate and human forcing on long-term trends in hypoxia in the Baltic Sea (as also pointed out by referee 1).

Specific comments:

1. Hypoxia in the Baltic Sea during the late Holocene period occurred between c. 2000-800 cal. years BP and subsequent to AD 1800 (Zillén et al. 2008). Due to the dating problems associated with radiocarbon measurements of bulk sediment samples in the Baltic Sea, these dates are associated with large uncertainties (up to $\pm$ 500-1000 years). As stated in the manuscript, better chronological control is needed to constrain the time-periods of hypoxia. However, based on current knowledge, the period of hypoxia during the last c. two millennia overlap with increases in land-use changes that took place during the Medieval expansion and the Industrial Revolution.

2. We do not translate population growth data from Sweden to the whole catchment. The population growth data is from the "Atlas of World Population History" by McEvedy and Jones (1978) as referred to in the text and figures.

3. We do not refer to coastal hypoxia because long-term trends of coastal hypoxia poorly known. A few studies in Finnish waters imply that sea-floor hypoxia has been present over centuries and millennia in coastal areas in the Archipelago Sea (Virtasalo et al. 2005; 2006) comparable to the open-sea hypoxia.

4. We will state more clearly and be more consequent when we define the different

time periods of change, as also pointed out by referee 1.

5. Temperatures have no proven effects on the oxygen conditions in the Baltic Sea and the relationship between primary production and climate change is not straightforward (Richardson & Schoeman, 2004). The link between phytoplankton abundance and sea surface temperature is only indirectly coupled to temperature. However, we do discuss the temperature effect on the stratification of the water column, especially during summers, and its influence on the growth of cyanobacteria. This section will be enlarged in the revised manuscript, as suggested by the referee.

6. We will more clearly separate between P and N and clarify that P is more important for the growth of cyanobacteria and N for the increase in phytoplankton biomass.

7. It is possible that the ancient rivers were more efficient in removing nutrients, as suggested by referee 2. This will be discussed in more detail in the revised manuscript along with additional references to nutrient release from soils in association with agricultural activities.

References:

Boynton, W.R., Garber, J.H., Summers, R. & Kemp, W.M. Inputs, transformations and transport of nitrogen and phosphorus in Chesapeak Bay and selected tributaries. Estuaries, 18, 285-314, 1995. Billen, G. and Garnier, J. The Phison River Plume: coastal eutrophication in response to changes in land use and water management in the watershed, Aquat Microb Ecol 13, 3–17, 1997. Bradshaw, E. G., Rasmussen, P., Nielsen, H., and Andersen, N. J.: Mid- to Late-Holocene land change and lake development at Dallund Sø, Denmark: trends in lake primary production as reflected by algal and macrophyte remains. The Holocene, 15, 1130-1142, 2005. Conley, D.J. Biogeochemical nutrient cycles and nutrient management strategies, Hydrobiologia 289, 87–96, 1999. Conley, D. J., Björck, S., Bonsdorff, E., Destouni, G., Gustafsson, B., Hietanen, S., Kortekaas, M., Kuosa, H., Meier, M., Müller-Karulis, B., Nordberg, K., Nürnberg, G., Norkko, A., Pitkänen, H., Rabalais, N., Rosenberg, R., Savchuk, O., Slomp, C. P., Voss, M., Wulff, F., and Zillén, L.: Hypoxia related processes in the Baltic Sea. Environ. Sci. and Technol., 43, 3412-3420, 2009. McEvedy, C. and Jones, R.: Atlas of world population history. Harmondsworth, Middx., Penguin Books, 19-119, 1978. Nixon, S. W. Prehistoric nutrient inputs and productivity in Narragansett Bay. Estuaries, 20, 253-261, 1997. Renberg, I., Bindler, R., Bradshaw, E., Emteryd, O., and McGowan, S.: Sediment evidence of early eutrophication and heavy metal pollution in Lake Mälaren, Central Sweden. Ambio, 30, 496-502, 2001. Richardson, A. J. and Schoeman, D. S. Climate Impact on Plankton Ecosystems in the Northeast Atlantic. Science 305, 1609-1612, 2004 Vahtera, E., Conley, D. J., Gustafsson, B. G., Kuosa, H., Pitkanen, H., Savchuk, O. P., Tamminen, T., Viitasalo, M., Voss, M., Wasmund, N., and Wulff, F.: Internal ecosystem feedbacks enhance nitrogen-fixing cyanobacteria blooms and complicate management in the Baltic Sea. Marine Ecology Progress Series, 36, 186-194, 2007. Virtasalo, J.J., Kotilainen, A.T., Räsänen, M.E. Holocene stratigraphy of the Archipelago Sea, northern Baltic Sea; the definitions and descriptions of the Dragsfjärd, Korppoo and Nauvo Alloformations. Baltica 18, 83-97, 2005 Virtasalo, J.J., Kotilainen, A.T., Gingras, M.K. Trace fossils as indicator of environmental change in Holocene sediments of the Archipelago Sea, northern Baltic Sea. Palaeoceanography, Palaeoclimatology, Palaeoecology 240, 453-467, 2006. Zillén, L., Conley, D. J. Andrén, T. Andrén, E., and Björck, S.: Past occurrences of hypoxia in the Baltic Sea and the role of climate variability, environmental change and human impact. Earth Sci. Rev., 91, 77-92, 2008.

Interactive comment on Biogeosciences Discuss., 7, 1783, 2010.