

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

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The manuscript is a follow up to Zillén et al. 2008 where the authors reveal the occurrence of hypoxia in the Baltic Sea during the entire Holocene. In the latter paper, the role of forcing mechanisms (climate and anthropogenic perturbations) on long-term shifts in bottom water oxygen conditions in the basin was discussed. This manuscript focuses on human impact and its possible impacts on hypoxia in the Baltic Sea during the last two millennia, with a specific emphasis on early human activity and its impact on the marine environment. This focus was selected because most (or all) previous paleoenvironmental studies of the Baltic Sea has explored ecosystem responses to climate forcing and not addressed additional forcing mechanisms, such as the impact of large land-use changes on nutrient availability, eutrophication and associated hypoxia.

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However, this is not an easy task since data on nutrient inputs to the Baltic Sea are only available for the last c. 50 years. Nevertheless, it is possible to examine and consider the evidence for such impacts to address the importance of human activities on the environment – not only on recent time-scales (which we know have caused increased eutrophication and expansion of the hypoxic zone) but also on long time-scales. This approach is critical in order to establish marine reference conditions to improve future management of the Baltic Sea environment. Referee 1, believes that we make a strong case for long-term human-related activities and their relation to eutrophication and hypoxia in the Baltic Sea. However, the referee asks for extended focus on the more recent time (post World War II) and more information on the geological history and the regional climate development in the Baltic Sea area. Therefore, in the revised manuscript we will (1) expand the section on the more recent time period (2) provide more information on the development of the Baltic Sea and (3) discuss the regional Holocene climate variability in more detail, which will assist readers that are not so familiar with the Baltic Sea.

Below follows more specific details on the revision:

1. We have provided evidence of human-caused activities from the vast majority of the countries surrounding the Baltic Sea (i.e. Sweden, Denmark, Finland, Germany and Lithuania). However, we will add a few references on prehistoric land-use changes and deforestation on a global and European scale (e.g. Kaplan et al. 2009 and Pongratz et al. 2008).
2. We will state more clearly and be more consequent when we define the different time periods of change.
3. The description of the geological history of the Baltic Sea and that its physical properties in the geological past differ from the last two millennia is already mentioned under section 2 (Occurrence of hypoxia in the Baltic Sea). However, this section will be expanded (see general comments above) and we will state this more clearly in the

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revised manuscript, as suggested by the referee.

4. We will change the title to “Hypoxia and cyanobacterial blooms are not natural features of the late Holocene history of the Baltic Sea”.

5. We will make clearer that the physical properties (i.e. its limited water exchange, long water residence times and large drainage area) of this enclosed sea makes it vulnerable to relative small changes in nutrient loads.

6. We will delineate more obviously the differences between the historic and the recent human impact on hypoxia in the Baltic Sea.

7. Abstract: We will delete the bulleted conclusion and incorporate them in the abstract. We will make the list of suggested changes by the referee.

8. 1. Introduction: We will (1) define hypoxia (2) explain that the geological evidence of hypoxia (i.e. laminations) do only reflect oxygen concentrations below 2mg/l and that it is not a direct measure of past oxygen levels (3) take away that “P is an airborne nutrient” (4) add “lower N/P ratios in the surface water” and (5) take into account the suggested changes of the text.

9. 2. Occurrence of hypoxia in the past: Apart from extending this section as suggested by the referee we will (1) explain “steep” and clarify how increased salinity affect the stratification of the water column (2) add (Meier and Kauker, 2003) as a reference to stagnation periods (3) add that “based on observations we know that an intensification of hypoxia has occurred after 1950” (4) change to northwestern Europe (5) explain late-Medieval crisis and high-Medieval (6) add years for late Holocene and (7) take into account the suggested changes of the text.

10. 3.1. Population dynamics: We will change the verbs to past tense.

11. 3.2. Technological development: We will (1) change Dowson to Dawson (2) change “nitrate leaching” to “organic N leaching” (3) change phosphate to TP (4) change “Fennoscandia” to “northern boreal forests” (5) change “tiling” to “tilling and (6) take

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into account the suggested changes of the text.

12. 3.3 Land use changes: We will (1) change “sophisticated” to “advanced” (2) change “probably” to “likely” (3) change “Boreal” to “boreal” (4) provide the identity of N and more data on modern N and P inputs to the Baltic Sea (5) include the doubling of arable land in fig. 6 (6) change “nutrient leakage” to “nutrient losses” (7) change “Northwestern” to “northwestern” (8) add a date on the increase use of fertilizer (9) add more data on artificial fertilizer use during the 20th century and (10) ) take into account the suggested changes of the text.

13. 5.1. Human forcing and climate change: We will (1) extend the text on the geological and climate development of the Baltic Sea in section 2, as suggested by the referee (2) we will delete lines 6-13 on page 15 as the referee suggest that these are not necessary (3) change “cyanobacteria blooms” to “cyanobacterial blooms” (4) provide nutrient load data for a longer time period and (5) take into account the suggested changes of the text.

14. References: We will make all the changes suggested by the referee.

15. Figures and Tables: We will make the recommended changes including (1) make the suggested changes in the legend in Table 1 (2) explain the age uncertainties associated with figure 2 and change the font (3) define major Baltic countries in the legend to figure 3 and adjust the scale (4) explain what happened in 1500-1600 (i.e. late-Medieval crisis) in figure 5 and (5) exclude figure 6.

References:

Kaplan, J. O., Krumhardt K. M. and Zimmermann, N.: The prehistoric and preindustrial deforestation of Europe. *Quaternary Sci. Rev.*, 28, 3016-3034, 2009. Meier, H.E.M., and Kauker, F. Sensitivity of the Baltic Sea salinity to the freshwater supply. *Climate Research* 24, 231–242, 2003. Pongratz, J., Reick, C., Raddatz, T. and Claussen, M.: A reconstruction of global agricultural areas and land cover for the last millennium.

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Global Biogeochem. Cycles, 22, GB3018, doi:10.1029/2007GB003153, 2008.

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

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