

## ***Interactive comment on “A 1500-year multiproxy record of coastal hypoxia from the northern Baltic Sea indicates unprecedented deoxygenation over the 20<sup>th</sup> century” by Sami A. Jokinen et al.***

### **Anonymous Referee #1**

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The authors presented a 1500-year multiproxy sedimentary record from the Archipelago Sea in the Baltic Proper. The records show a progressive eutrophication in the region and a pronounced aggravation of bottom water hypoxia in the 1950s, which is unprecedented. This is interesting and merits publication. However, the authors fail to convince me that between 900 and 1900 the multicentennial variability of the bottom water oxygen concentration was locally forced. Furthermore, it remained puzzling how the combined effects of gradual shoaling of the basin and warming climate amplified sediment focusing and increased the vulnerability to hypoxia. This however appears to be crucial to authors since they conclude that: ‘such natural changes should be considered when elucidating anthropogenic contribution to hypoxia’ I would suggest to

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include C/N ratios,  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of soil organic matter into discussion and most importantly into the mixing analyses used to quantify inputs of terrestrial organic matter.

Please find further comments below:

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Authors: (Fig 5) Indeed, despite the negative long-term trend in autochthonous OM concentration from the pre-MCA towards the present, the MCA and MoWP are typified by relatively high input in comparison to the LIA, implying enhanced productivity under warm climatic phases.

This is difficult to see in the figure 5. If at all the declining OM concentration hold on until about 1700 and not towards the present. Assuming that OM% indicates primary production why OM% during the MoWP does not exceed those during the MCA despite heavy eutrophication and global warming after 1900.

Authors: By contrast, a distinct decrease in Corg and  $\delta^{13}\text{C}_{\text{org}}$ , paralleled by an increase in C/N and BIT index, coincides with the MCA– LIA transition (Fig. 5), suggesting that this marked decline in local primary productivity was most likely forced by the climatic cooling (Kabel et al., 2012).

The use of OM% as productivity indicator and ignoring Corg MAR is problematic and calls for further explanation justifying this interpretation.

Page 20 Authors: However, this period is characterized by a shift to suppressed primary productivity at our study site, implying no influence of enhanced external nutrient inputs.

Decreasing OM% and increasing BIT implies to me that an enhanced input from land could have lower OM% because of dilution. Since at this time grain sizes decrease this might be a response to enhanced aeolian dust inputs due to the expanding agriculture at around 1400. Which role could the changing sediment structure play with respect to the preservation of OM in the sediment?

Authors: The lack of anthropogenic forcing of OM input during the MCA is also evidenced by the constant sediment  $\delta^{15}\text{N}$  signature over this period at Haverö (Fig. 5; see also Cole et al., 2004).

Impacts on  $\delta^{15}\text{N}$  I would expect only in response to an intensive use of fertilizer which occurred much later as indicated by the provided data. I would expect an enhanced soil erosion, that is why I suggested to integrate C/N ratios and  $\delta^{13}\text{C}_{\text{org}}$  of soil organic matter.

Page 20 Authors: Yet, we observe negligible changes in the source of OM around 1900 AD, as implied by the relatively constant C/N and  $\delta^{13}\text{C}$  values (Fig. 6). This suggests that the strong increase in the Corg MAR at this time was mainly caused by intensified sediment focusing, as supported by the contemporaneous increases in Ti/K and sediment MAR (Figs. 4 and 6). We propose that the general trend towards higher source-to-sink ratio in the basin, combined with the climate-driven intensification of wind-induced sediment reworking (Fig. 6) to increase the Corg MAR to the sediments

I would argue that a stronger physical forcing in addition to waste water discharges (enriched in  $^{15}\text{N}$ ) increased the marine productivity which decreased BIT, C/N ratios and  $^{13}\text{C}$  values as seen in your data.

Authors: By contrast, the shift to unprecedentedly heavy  $\delta^{13}\text{C}$  signature, sympathetic with a decrease in C/N and BIT index around 1950 AD (Fig. 6), points to direct enhanced export production of phytoplankton-derived OM at this time (Meyers, 1994; 1997; Hopmans et al., 2004).

I agree but this occurred already before but on a lower scale.

Page 21 Authors: We attribute the multicentennial-scale fluctuations in bottom water oxygenation associated with the MCA and LIA to climatic variability that modulated both hydrographic conditions and accumulation of OM at the sea floor.

It is not clear on which data this statement is based.

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Page 23 Authors: Considering the negligible variation in the proxies for the source of OM prior to 1930 AD (Fig. 6), the onset of seasonal hypoxia and the resulting preservation of continuous lamination since the beginning of 20th century was apparently not forced by changes in primary productivity. Instead, we postulate that this deoxygenation was forced by the following complex interplay of warming climate and millennial-scale changes in the basin configuration:

To me your data are showing that eutrophication increases primary production and hypoxia.

Page 23 Authors: Accordingly, although we can not completely exclude the possible contribution of anthropogenic forcing, the onset of recurring seasonal hypoxia at around 1900 AD can be largely attributed to the naturally increased vulnerability to deoxygenation that together with global warming irreversibly tipped the ecosystem over a threshold, inducing a regime shift commonly associated with coastal oxygen deficiency (e.g. Conley et al., 2009b).

I would say the opposite: anthropogenic forcing seems to be the decisive factor but you cannot rule out others processes.

Page 24 Authors: We postulate that, in addition to effective sediment focusing, the increased sediment MAR was likely fueled by ballasting effects, whereby eutrophication-induced increase in the OM production in the euphotic zone drives the sedimentation of fine-grained lithogenic material through aggregation (Passow, 2004; Passow and De La Rocha, 2006; De La Rocha et al., 2008), as suggested by the close covariation between sediment and Corg MARs (Fig. 6).

This part sound also odd: What fuels the ballast effect?

Page 25 Authors: Our data show that environmental conditions in some areas of the Archipelago Sea likely deteriorated several decades prior this, and therefore also prior the establishment of water quality monitoring campaigns in the 1960s.

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Not at some areas only at your study sites.

Our  $\delta^{15}\text{N}$  record demonstrates increased anthropogenic nutrient input already at the beginning of the 20th century (Fig. 6), although the onset of hypoxia and laminated sediment deposition at this time was likely driven by other factors (Sect.6.3.2).

If you would replace 'likely' with 'additionally' I would almost agree.

Page 25 Conclusion Authors: This study shows that multicentennial-scale climatic oscillations affect near-bottom water oxygenation of a shallow coastal basin in the northern Baltic Sea currently suffering from severe seasonal hypoxia. During warm phases, increased export production of labile, phytoplankton-derived OM combined with effective sediment focusing to the deepest part of the basin drive deoxygenation of the near-bottom waters in summer.

Based which data you define 'labile' To my understanding 'sediment focusing' should favor the accumulation of more refractory OM and considering the declining CorgMAR until 1900 I doubt that changes in bottom water concentration are locally forced.

Authors: The progressive deoxygenation during the 1900s was originally triggered by gradual shoaling of the basin due to glacio-isostatic uplift and basin infilling that, together with warming climate, intensified OM delivery primarily through enhanced sediment focusing.

Please clarify: What fills the basin, from where the filling comes what do you expect climate to do!

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