

Interactive comment on “Historical records of coastal eutrophication-induced hypoxia” by A. J. Gooday et al.

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We thank review #3 for these helpful comments. The comments themselves are repeated below, followed by our response.

Comment #1. In the manuscript, the focus is made on recent hypoxia related to anthropogenic forcing. However, the hydrographical context (stratification, vertical mixing, and bottom water temperatures for example) plays a determinant role independently from anthropogenic effect. Therefore, it would be helpful to add a short section (in or after the introduction) to describe what are natural conditions favourable to hypoxia, to summarize which are the physical, chemical and biological parameters fostering hypoxia and what are the areas of the world that are the most sensitive or vulnerable, with regard to hypoxia due to productivity, ocean or climate changes.

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Response. We agree that other factors are involved in the creation of hypoxia. However, these are treated fully by Levin et al. in a paper in the same volume. We have therefore confined our response to the addition of the following passage at the end of the Introduction (lines 112-120) – ‘In addition to natural and anthropogenic eutrophication, hydrographic factors often help to intensify and maintain bottom-water hypoxia. Such factors include the isolation of deeper water masses by stratification of the water column or geographical confinement, and the advection of low-oxygen water from other sources (see Levin et al. in press for a full treatment of this topic). In parts of the Baltic Sea, hypoxia during the Holocene and the modern era has been closely linked to water-column stratification caused by climate-related fluctuations in river runoff and salt-water inflows, although eutrophication has also been an important driver, particularly during the last 50 years (Laine et al., 2007; Zillén et al., 2008).’

Comment #2. The examples of application are very interesting, but difficult to follow. A map accompanying table 1 and showing the location of the case study discussed in the text would help.

Response A map to accompany Table 1 has been added as Fig. 1

Comment #3 The interpretation of proxies in terms of hypoxia often depends on the local or regional context. A given tracer can be interpreted differently from one area to another and none is unequivocal. It would be useful to make sort of hierarchy of tracers and to distinguish those which are more universal from those which are equivocal (in an additional column of table 2, for example).

Response. The faunal tracers are probably more influenced by local conditions than the chemical tracers. The entries in Table 2 for foraminifera and dinocysts have been modified to make this point. We have also added a point to the final section (6, lines 1374-1376). However, it is difficult to make a hierarchy of tracers.

Comment #4 Tracers and proxies of "productivity" do not necessarily provide insight into "eutrophication" since high productivity does not necessarily lead to eutrophication

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(in upwelling areas for example). This should be clarified in chapter 4 and Table 2.

Response. The term 'eutrophication' refers to nutrient enrichment leading to elevated production of particulate organic matter and in some cases hypoxia. This is clarified in the first sentence of the introduction. The reviewer says that high productivity does not necessarily lead to eutrophication, and refers specifically to upwelling areas. Perhaps the point being made here is that eutrophication does not necessarily lead to organic enrichment of the sediment or bottom-water hypoxia. We have added the following sentences at the beginning of section 4 (lines 736-739) to illustrate this point with reference to the NW African upwelling area – 'It should be noted that, although eutrophication often leads to bottom-water hypoxia, this is not always the case. For example, off NW Africa, natural eutrophication caused by upwelling leads to very high levels of primary production, and yet oxygen concentrations in the underlying bottom water remain relatively high (Jorissen et al., 1998).'

Comment #5 page 2571. There is a statement about the correlation between hypoxia and eutrophication, which is relevant. It is my understanding that severe eutrophication results generally in hypoxia, but the contrary is not necessarily true since hypoxia may develop without eutrophication. Is this correct ? A few sentences could help to clarify the question.

Response. This is related to point #1. We have added a sentence about water-column stratification as a driver of hypoxia in the Baltic, to the two new sentences mentioned above.

Comment #6 Both terms "proxies" and "tracers" are used throughout the text. What is the distinction between these 2 terms?

Response. In the original text, we used these terms interchangeable. Strictly, the term 'proxy' should be applied to quantitative or semi-quantitative indicators of past environmental parameters, whereas a tracer is a more generalised indicator (see definitions in Hillaire-Marcel and de Vernal, 2007, Methods in Late Cenozoic palaeoceanography:

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introduction. In: Hillaire-Marcel, C. and de Vernal, A. (Eds.), *Proxies in Late Cenozoic Paleooceanography*, Elsevier, Amsterdam, pp 1-15). However, in the historical literature, proxy is often used for all types of indicators, qualitative as well as quantitative. Apart from one place (line 362), we have therefore eliminated the term 'tracer' and added a sentence (line 134) to make clear that we are using proxy for both qualitative and quantitative indicators.

Comment #7 A table with a list of taxa tolerant to hypoxia and taxa intolerant to low dissolved oxygen concentration would be useful in section 3.1.

Response. This section is about faunal indicators of hypoxia that are preserved in the fossil record. There are really only two of these, foraminifera and ostracods. There is no need to review responses of taxa that are not preserved. Levin et al. (same volume) review the tolerance of modern organisms to hypoxia. For these reasons, we have decided not to include a table.

Comment #8. page 2580, lines 10-18. A recent decrease in the isotopic composition of biogenic carbon probably results from the decrease of ^{13}C in atmospheric CO_2 due to the combustion of fossil fuel with low ^{13}C values (Suess effect). Therefore, the interpretations reported here might be wrong.

Response. Following sentence added near end of section 3.1.1. (lines 371-373) – 'However, these trends could also reflect the decrease in ^{13}C in atmospheric CO_2 caused by the consumption of fossil fuel with low ^{13}C values, the so-called Suess effect (Suess, 1955; Verburg, 2007).'

Comment #9. page 2595. What about the preservation of opal depending upon sedimentation rates, temperature and saturation of water in SiO_2 ?

Response. Essentially everywhere in the ocean is undersaturated with respect to opaline silica. The effects of temperature and salinity are minor compared to this. The only place that silica concentrations approach saturation are within the sediment.

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The sedimentation rate will influence the amount of siliceous material available to saturate the pore waters. Tests may be better preserved in areas of high siliceous flux, due to the fact that a small fraction of the settling material would have to dissolve to saturate the pore waters. However, on p. 2595 we are concerned with biologically bound silica, not with the preservation of discrete biogenic opal particles, and so we don't feel that these factors are relevant.

Comment #10. pages 2597-2598. There are interesting studies dealing with dinocysts and productivity which were recently published (cf. for ex. Radi et al., Marine Micropal. 2007, 2008) notably in a recent issue of the Marine Micropaleontology (vol. 68, no 1-2).

Response. References to these and similar papers have been included in sections 4.1.2. (lines 823-824, 828-831) and 6 (line 1372)

Comment #11. Figure 4. Is the A-P index higher when agglutinated foraminifers dominate ? I am not sure to understand.

Response. Thanks for pointing this out. The caption was wrong and has been corrected.

Comment #12. Figure 6. Almost impossible to read.

Response. Hopefully, this figure should be OK when viewed on a screen or in the printed version.

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