

## ***Interactive comment on “Looking beyond stratification: a model-based analysis of the biological drivers of oxygen depletion in the North Sea” by F. Große et al.***

**F. Große et al.**

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Dear referee,

first of all, we would like to thank you for the positive reception of our manuscript, the thorough reading and the constructive criticism.

In the following we will go through the points you raised, including some initial feedback.

List of issues:

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### **- general points:**

**1.** The manuscript is too long and needs shortening.

**- reply:** We agree on that point and already thought about which parts of the manuscript could be shortened or moved to an appendix to reduce the length of the main manuscript. Namely, we will try to shorten the methods section (model description and description of observation data) by removing some of the details or referencing to previous publications (where applicable). In addition, we intend to move section 3.1 “Evaluation of the stratification and MLD criterion” (including Fig. 3) to an appendix as this is less important to follow the story of the study. However, as it differs significantly from other MLD criteria we consider it necessary to provide this evaluation. Section 3.2.3 “A quantitative assessment of the model performance can also be shortened by removing the Equations (3), (4) and (5), and referencing to Taylor (2001) instead. We are also considering to move one of the figures showing the mass balances to the appendix (e.g., Fig. 9) and to shorten the corresponding section.

**2.** The context of the paper needs to be clarified, i.e., clear distinction between hypoxia and O<sub>2</sub> deficiency.

**- reply:** You are right that O<sub>2</sub> levels of about 6 mg L<sup>-1</sup> (= OSPAR threshold for O<sub>2</sub> deficiency) are well above the levels considered as hypoxic. Thus, we will avoid the term “hypoxia” in the updated manuscript. However, as you already pointed out, e.g., Vaquer-Sunyer and Duarte (2008) argued that such higher levels can already have negative effects on the marine fauna. In this context, also Topcu et al. (2009) discussed that the OSPAR threshold for O<sub>2</sub> deficiency is too low as substantial negative effects on the biology already occur at these higher concentrations.

**3.** Focus the study on the question whether North Sea O<sub>2</sub> levels indicate O<sub>2</sub> deficiency or just background levels of seasonally stratified shelf seas?

**- reply:** This definitely is an interesting question, however, such study would require the conduction and analysis of a reference model scenario, e.g., representing pre-industrial (“pristine”) conditions. This would go beyond the scope of our present

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work, and we therefore prefer to stick to the current focus of our study. The current scope is to demonstrate that biogeochemical models are capable of reproducing well observed O<sub>2</sub> concentrations (in the North Sea) and by this provide a temporally and spatially consistent picture of the O<sub>2</sub> dynamics. This can help monitoring authorities to create an optimised setup of monitoring campaigns as you also pointed out in your comments. The second focal point of our work is to show the large value of the ability of these models to quantify the different physical and biological processes driving the O<sub>2</sub> dynamics. By this we can analyse why low O<sub>2</sub> conditions do or do not occur under similar conditions of stratification and in different regions of the North Sea. Furthermore, this provides valuable information for the better interpretation of O<sub>2</sub> observations as Greenwood et al. (2010) also pointed out regarding the SmartBuoy data.

**- specific points:**

**1.** Definition of “low oxygen conditions” at the beginning of the introduction.

**-reply:** Our definition of low O<sub>2</sub> conditions implies values of less than 6 mg L<sup>-1</sup>, which is the OSPAR threshold for O<sub>2</sub>. We will clarify this in the introduction. As mentioned above we will also remove the term “hypoxia” to avoid confusion.

**2.** A conceptual map of the three regimes/zones should be included.

**-reply:** This is a very good suggestion and we aim to provide a map of the North Sea which summarises the outcome of the characterisation of the three regimes/zones (section 3.4) and extends this to the whole domain, by using the key factors affecting bottom O<sub>2</sub>. Such map would provide valuable information on the likeliness of low O<sub>2</sub> conditions in the North Sea, and thus perfectly meets one of the key aspects of our study (see reply to general point 3).

**3.** Shorten methods section.

**-reply:** We agree that there is some space for shortening in this part of the manuscript as already indicated in your comments and in our reply to the first general point.

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**4.** The low temporal variability in the simulated bottom O<sub>2</sub> during late summer indicates that measurements conducted during this period provide a synoptic picture of the O<sub>2</sub> situation of the North Sea system. This is an important aspect for the monitoring authorities.

**-reply:** We are glad that you received this aspect that favourably. Thus, we will refer to this in the conclusions section as one of the key findings of our study.

**5.** Should the hypothesis be built around the understanding of the reasons for different O<sub>2</sub> development under similar stratification conditions rather than focussing on why there are low O<sub>2</sub> conditions in the bottom layer?

**-reply:** The first point you mention is exactly what we are aiming for, and for which reason we calculated the O<sub>2</sub> mass balance for one area for 2002 and 2010, two years of very similar stratification but very different O<sub>2</sub> development. However, it seems like this point was not made clear enough in the current manuscript, thus we will clarify this in the updated version.

**6.** Include average water column depth, maximum MLD and O<sub>2</sub> concentrations at end of stratification in Table 1.

**- reply:** That is a good idea and can be done easily. However, the maximum MLD does not add much to the discussion as it was identical for all areas. Instead, it may be helpful to provide the area-weighted average MLD so that the reader may construct a mean water column if needed. Considering the average water depth and O<sub>2</sub> concentration at the end of the summer period, we agree that these are useful information. The first one is especially helpful in relation to the conceptual map (see specific comment 2) as it directly affects the sub-MLD volume which is a critical quantity for the development of low O<sub>2</sub> conditions. The latter one is useful as the difference between the final and initial concentration provides an indicator for the O<sub>2</sub> consumption in the different areas.

**- technical corrections:**

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1. Abstract, line 12: "is bottom layer not always below thermocline?"

- **reply:** We will rephrase this sentence as we wanted to differentiate between the analysis of the whole sub-MLD volume and the bottom layer only. In addition, in well-mixed regions the bottom layer is not below the thermocline as there is no thermocline.

2. Page 12546, line 7: "indicates that respiration only occurs below the thermocline, which is obviously not the case"

- **reply:** With this we only intended to say that in the upper layers of stratified waters production usually surmounts respiration and vice versa in the deeper layers. However, as depending on season respiration in the upper layers can even exceed production, we will rephrase and clarify this sentence.

3. Page 12547, lines 6-18: "reference to oxygen depletion and low oxygen concentration but no information on the corresponding concentration that was observed? Please provide information on concentration if available"

- **reply:** We will do this, where available.

4. Page 12547, line 22: "In relation to figure 1 and use of the <6 mgL-1 is much higher than the normal hypoxia threshold. Even if we acknowledge that biological impacts may occur at levels above the lower hypoxia threshold levels closer to the 6 mg L-1 threshold are likely to have minimal impacts on organisms that are resident in stratified environments."

- **reply:** We will avoid the term "hypoxia"/"hypoxic" throughout the manuscript.

5. Page 12556, line 11: "Why use the phrase so-called?"

- **reply:** We will remove this.

6. Page 12563, line 1: "state the values rather than say less than?"

- **reply:** Yes, we will list the actual value.

7. Page 12569, line 7: "yellow boxes?"

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- **reply:** Yes, it must indeed read as "yellow boxes" instead of "red boxes".

8. Page 12572, line 16: "give the rate value."

- **reply:** We will include the actual value.

With this we would like to conclude and thank you again for your helpful comments.

Kind regards  
Fabian Große

on behalf of all authors

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