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# *Interactive comment on* "Consequences of artificial deepwater ventilation in the Bornholm Basin for oxygen conditions, cod reproduction and benthic biomass – a model study" *by* A. Stigebrandt et al.

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The authors are grateful to Referee #1 for a thoughtful and constructive review. Below we respond to comments and suggestions by the referee and we also present changes in our manuscript brought about by the comments. Comments by the reviewer are marked by R, authors responses are marked by A and changes in manuscript are marked by M.

R P C691 L1-5: ". . . I found the final discussion to be lacking slightly. Discussions of cod recruitment and benthic biomass seemed disjointed after such a solid start. Output from models indicated changes in habitable volume/surface area for cod and benthic biomass, but deeper conclusions debating longer term effects, stability of observed changes and interactions were limited."

A: We agree and make the following changes in manuscript.

M: On P 1805 L1 we add: "The bottoms deeper than 75 m, with an area of about 5000 km2, will be habitable for benthic biomass as further discussed in Section 4.6". On P.1808 below L2 we add: "The oxygenation of the deepwater in the Bornholm Basin may only marginally change the supply of organic matter and the oxygen consumption in the basin water beneath the sill depth as explained above*. The changes in hydrography and oxygen conditions induced by pumping will therefore be lost when the pumps are turned off for a longer period or permanently." On P1813 L27 we add: "The increase of biological production since the 1950s is the main reason for present day hypoxia and anoxia. Oxygenation of the Bornholm Basin cannot change this but can be used to improve the oxygen conditions in the deep part of the basin and thereby also make the deepest parts habitable. However, as long as the biological production is not reduced, the oxygen conditions in the Bornholm Basin will return to present time conditions if the pumping is shut off. A reduction of the large-scale eutrophication might possibly be achieved by restoration of the Baltic Proper which would require oxygenation of all anoxic bottoms in the Baltic Proper. This will be discussed in a forthcoming paper."

*refers to the new paragraph on P 1806 below L 24 presented below. (This comment will of course not be included in the manuscript)

R P C691 L 5-8: "Almost no mention was made on impacts on the surface layer and what this may have seasonally, particularly in the nutrient limited summer surface waters and how this may then impact cod recruitment and benthic biomass."

A: We agree and make the following changes in manuscript.



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M: On P 1806 below L 24 we add a new paragraph: “The changes in salinity due to pumping can easily be seen in Fig. 6 in Stigebrandt and Kalén (2012), which shows that the pumped winter water, of salinity about 8, is interleaved in the lower part of the halocline, well below 60 m depth, due to strong mixing with the ambient deepwater. When interleaved, the volume flow of the pumped plumes has increased by a factor of 20 to 30. Equally strong mixing of the pumped flow was observed in the By Fjord experiment where the volume flow of pumped plumes increased by a factor of 30 before they were interleaved (Stigebrandt et al., 2014). Because the pumped water is interleaved in the lower part of the halocline, the dynamics of the surface layer, including the local supply of nutrients and the production of organic matter, should be negligibly influenced by the pumping. However, since the oxygenation reduces the leakage of phosphorus into the deep-water of the Bornholm Basin (Stigebrandt et al. 2013), this water will carry less phosphorus with it when it is flushed and further transported into the basins east of the Bornholm Basin. Consequently there will be a decreased upwelling of P in the basins east of Bornholm Basin. The effect of decreased P-loading of the Baltic Proper will eventually also be felt in the surface layer of the Bornholm Basin, as an indirect effect of the pumping, and lead to a decreased production of organic matter sinking down into the deep basin. This will be beneficiary to cod recruitment since the oxygen consumption decreases in the deep-water. The benthic biomass will get less feed falling down from the surface layers.

R P C691 L 9-12: As the reader is also likely to not be fully acquainted with the original model, the reader needs a bit more convincing that the tuning was successful. 10% error in salinity between hydrographic profiles and pool model seems a bit high. Can the authors justify that this is a negligible difference?

A: Here we lean on an earlier investigation and add the following text in manuscript.

M: On P1801, L 17 we add the following text: “However, it was shown in Stigebrandt (1987a) that due to the large variability of the flow of new deepwater in Arkona Basin, about 500 independent observations are needed to estimate the mean inflow with an



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error less than 10%. Thus, from the number of observations available (451, see Section 3.1) we expect an error within the range ±10 %. This means that the computed flow might be closer to reality than statistics produced by the observations. The evolution of observed and modeled vertical distributions of salinity, temperature and oxygen shown below, may deviate rather much due to the combination of large variability and sparse observations. Another reason for deviations is the fact that model results are from a horizontally integrated model with high temporal resolution while observations are obtained at a few depths of a sparsely visited location (BY4)."

R P C691 L 12-13: How robust are the model results when inflow is not low-pass filtered or with a different buffer volume?

A: The low-pass filter and the buffer volumes are included to cover up for lack of horizontal resolution of the model. They cannot be removed as discussed in Stigebrandt (1983).

R P C691 L 13 – 14: Could an additional figure like 4 and 5 be added describing temperature or density?

A: We will add a new figure, here denoted Figure A, showing the temperature since density would be very similar to salinity figures (because salinity changes dominate density changes).

M: On P 1788 L2 we add ", temperature" after "salinity". On P 1801 L 20–22 we remove the sentence "The model also describes the temperature . . . (not displayed)". On P 1802 L 2 we add the following text: "The observed and modeled temperatures are shown in Fig. A. It is obvious that the modeled temperature (Fig. Ab) in the halocline (50 – 65 m depth) often is too low in summer and too high in winter compared to the observed temperature (Fig. Aa). One reason for the deviation in winter may be that our model lacks surface dynamics and deep vertical convection occasionally reaching down to the sill level. Deviations all around the year may be due to too sparse data in the entrance area where water temperatures are given by monthly means meaning



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that inflows with extreme temperatures are missed. However, since density variations in Bornholm Basin are dominated by salinity variations it is of little dynamical importance that the modeled temperature is smoothed.

M: On P 1826 we add the following text: “Figure A (a) The measured temperature from BY4, (b) the modeled temperature (reference run) and (c) the modeled temperature when pumping 1000 m3 s-1 from 30 m depth down to 90 m.

M: On P 1826 we add Figure A.

Specific comments

R P1794 L26-27: A sentence detailing the density in time and space of observations would be beneficial here or indicating to the reader that this will be detailed further on.

A: The observational data we use to describe the upper layers, above 30 m depth, are obtained at BY4 (361 vertical profiles) as described on P 1798 L 26-27. From these profiles daily values are interpolated as mentioned on P 1798 L 7-9.

M: On P 1974 L 27 we add: “, see Section 3.1 below.” On P 1799 L2 we add the following text: “The vertical resolution varies throughout the profiles (decreases with depth) and also somewhat between profiles, due to missing data values. The most common resolution is 5 m between 0 - 20 m depth and then 10 m resolution down to 90 m. Data gaps are more common in the winter, when storms and ice cover stop the observation vessels from reaching the stations.”

R Eq. 11: “More justification is required to explain why you use the 1.5mL L threshold specifically. Whether B is constant or variable throughout the interval and why this is no longer necessary in anoxic conditions.”

A: On P 1801, L1-2 it is stated that the oxygen consumption is halved in the interval 0 - 1.5 mL/L. The reason for this is that the computed oxygen consumption then corresponds well to the observed (i.e. B=0.5). The limit value was set to 1.5 mL/L since it gave the best correspondence between model results and observations. Although interesting, we found no strong reason to fine-tune the parameterization by letting B vary in the interval 0 - 1.5 mL/L or using a B-value different from 1 in the anoxic case in the present paper. It is outside the scope of the present paper to go deeper into the details determining B. This is postponed to a future paper.

M On P 1801, L 2 we add the following: "Although interesting in itself, we found no strong reason for the present investigation to fine-tune the parameterization of oxygen consumption by, for instance, letting B vary in the interval 0 - 1.5 mL/L or using a B-value different from 1 in the anoxic case."

R Sec. 2.2.1: "The review of macrofaunal tolerance of hypoxia may serve better within the introduction to keep background information and methods separate, although this is more a matter of personal preference."

A: We think it reads better as it stands.

R P1796 L6-9: "I'm not sure I agree with this statement. I would avoid saying animals are adapted to living in anoxic conditions within the OMZ. Species diversity is reduced and the majority of macrofauna cannot survive within the region but instead uses the OMZ either as a refuge or hunting ground. And some macrofaunal species have begun to adapt to the hypoxic conditions within the Baltic."

A: The evidence that the benthic animals have adapted to conditions close to zero oxygen in OMZ is shown in the extensive review by Levin (2003). No live animals have been found in such low oxygen concentrations in Scandinavian waters as far as one of us (RR; R. Rosenberg) knows. The Referee is correct that species living in OMZ have a refuge against predation from less tolerant predators. The referee suggests that also in the Baltic adaptation to low oxygen conditions has occurred. RR is not aware of any such scientific study.

R P1801 L21: "Comparison of additional variables may help increase reader confidence in relevance of the model output."



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A: As already mentioned above we will also show temperature.

R P1803 L23: “Sentence does not read well”

M: The sentence on P 1803 L23 and the following sentence are changed to: “This layer has lower oxygen concentration than the surrounding water, why oxygen efficiently will diffuse into the layer from both above and below. Hereby the oxygen content is expected to increase already before the water in this layer exits through the Bornholm Channel.”

R P1806 L19: “Again it may help to have a few panels in figures showing other variables – at least temperature.”

A: Temperature plots added as described above.

R 4.6 and 4.7, first part: “These two sections feel disjointed from the previous parts. Numbers are provided for potential increases in benthic biomass and community changes, but these are not discussed in terms of impacting on cod recruitment. A small paragraph discussing or suggesting how this new biomass could affect cod recruitment, how the potential lack of diversity would affect recruitment, and how this would be different to a stable community would be interesting.”

A: We agree and will add the following small paragraph to the manuscript.

M: On P 1809 we will add a new paragraph between lines 11 and 12: “The recruitment of benthic animals into pre-hypoxic areas with a low diversity may be facilitated by the fact that only few niches are preoccupied and competition low. Initially the new recruits are likely to have a high production and demersal fish such as cod could benefit from the new food source.”

R 4.6 and 4.7, second part: “Two other aspects which I felt would be interesting to mention as the questions often came up when reading were the feasibility of pumping such volumes and what effects it may have on surface waters. Namely, what would the impacts of pumping more nutrient rich water to the photic zone during the summer be?



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Interactive Comment

Has anyone assessed the impact of surface production? Neither require much depth or discussion, but indicating relevant material or showing what work may (or may not) have been done would be nice."

A: The feasibility of pumping such volumes is discussed in reports that can be downloaded from www.box-win.se . As already discussed above in connection with referees comment on P C 691 L 5-5, the surface layer will not be directly affected because the local vertical circulation induced by the pumping is limited to the water layer between the winter water and the depth where pumped water is discharged. The impact on surface production should therefore be small.

Technical Comments

R Abstract P1784 L3-8: "'By pumping . . . new oxygen-rich deepwater' sentence should be split or simplified for the abstract."

M: P 1784 L 3-8, the sentence will be rewritten as follows:" By pumping well oxygenated so-called winter water to the greatest depth, where it is forced to mix with the resident water, the rate of deepwater density reduction increases as well as the frequency of intrusions of new oxygen rich deep-water."

R Abstract P 1784 L11: "Since it has been much less in certain years"

M: Changed as suggested.

R P 1784 L14-17: "Evidence?"

A: There is evidence in several scientific papers that re-oxygenation of sediments leads to increased P retention. For instance in the Bornholm Basin where natural re-oxygenation occurs, see Stigebrandt et al. (2013). We remove the words about bioturbation activity.

M: P1784 L 16. We delete the following text: "the bioturbation activity and"

R P 1784 L24-26: "Citation may be helpful here."



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A: It is not necessary here to explain why large volumes of the deepwater lack oxygen since the mid- 1990s. We delete text as shown below.

M: On P 1784 L 24 we delete: "Because of the restricted water exchange, an increased input of nutrients". On P 1784 L 25 we delete: "and a halocline at 60 – 80 m depth,".

R P 1790 L19: "Avoid abbreviating "e.g." in the ext"

M: We will change this.

R P1796 L16-18: "The sentence could be clarified and developed slightly."

A: We think it reads fine.

R P 1796 L 19: "I would suggest "pre-pollution levels" instead of "pre-pollution times"."

M: We will change as suggested.

R P1803 L23 (should be L13): "I would suggest listing the value in mL L in the text and providing the mg L value in parenthesis. As it stands, the reader must make the mental calculation to obtain the mL L value and compare it to others in the paper."

M: The following changes will be made:

M: P1803 L13: 0.47 mg L-1 will be replaced by 0.33 mL L-1 (0.47 mg L-1)

M: P1803 L27: 9.8 mg L-1 will be replaced by 6.7 mL L-1 (9.8 mg L-1)

M: P1806 L3: 3.9 mg L-1 will be replaced by 2.7 mL L-1 (3.9 mg L-1) and 9.8 mg L-1 replaced by 6.7 mL L-1 (9.8 mg L-1)

M: We will also change columns 6 and 8 in Table 1 as shown below

O2 (A)* / O2 (B)*

0.90 (1.29) / 2.28 (3.25)

1.57 (2.24) / 2.80 (3.99)



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1.09 (1.55) / 2.42 (3.46)

1.50 (2.14) / 2.74 (3.91)

1.69 (2.41) / 2.89 (4.12)

1.20 (1.71) / 2.50 (3.57)

1.46 (2.09) / 2.70 (3.86)

1.82 (2.61) / 2.99 (4.27)

1.53 (2.18) / 2.77 (3.95)

1.33 (1.90) / 2.61 (3.72)

*Oxygen values are given in mL L-1 (mg L−1 ).

R P1806 L17: “beneficial” as opposed to “beneficiary”

M: We will change as suggested

R: Fig. 2 and 3: It seems to me the captions have been mixed around.

M: True, we will correct.

R: Figs.: Red and green can be a very awkward color scheme for some colorblind readers. Fig. 6 in particular.

M: On P 1826 we will paste a new version of Fig. 6 with changed colors.

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Interactive comment on Ocean Sci. Discuss., 11, 1783, 2014.



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Interactive Comment

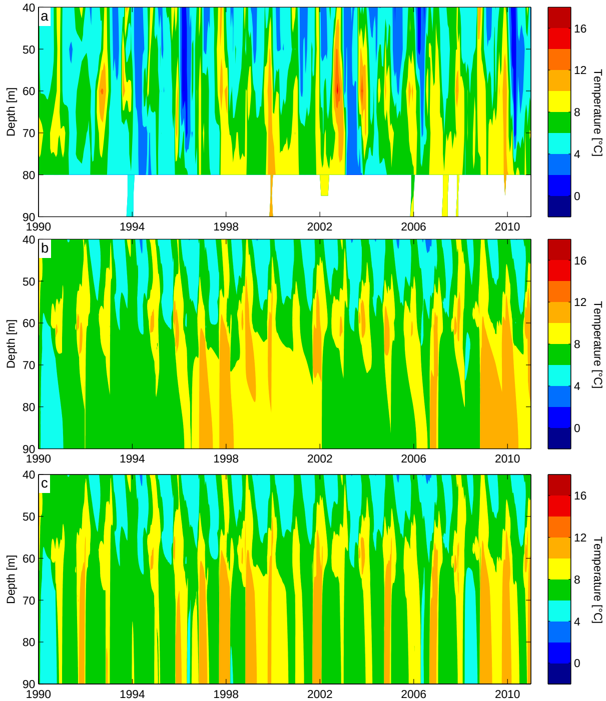


**Fig. 1.** Figure A (a) The measured temperature from BY4, (b) the modeled temperature (reference run) and (c) the modeled temperature when pumping 1000 m3 s-1 from 30 m depth down to 90 m.



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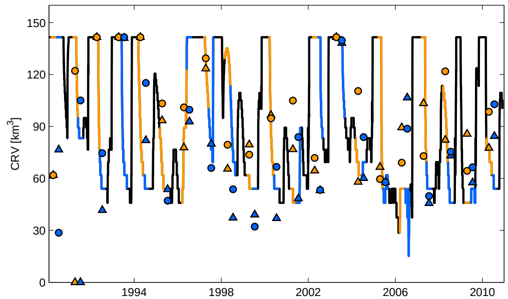


**Fig. 2.** Figure 6. same caption as on P1826 but with yellow instead of green and blue instead of red.



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