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# *Interactive comment on* "A Baltic Sea estuary as phosphorus source and sink" *by* Jakob Walve et al.

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Authors' response (AR) to comments by referee 2 (RC)

RC: "The manuscript by Walve et al. is a local study investigating whether the Stockholm inner Archipelago acts as a source or sink for phosphorus. They use a four-level box model based on observations to calculate the inflow and outflow of phosphorus to and from the study area as well as to calculate the retention of phosphorus within the area. The study is interesting and the manuscript is overall easy to follow." AR: We are pleased that our study was overall found interesting and the manuscript easy to follow, and are thankful for the constructive comments.

RC: "The title is not specific enough, since it is a local study in a limited area and

not valid in the entire Baltic Sea." AR: We suggest expanding the title to "A Baltic Sea estuary as phosphorus source and sink after drastic load reduction: seasonal and long-term mass-balances for the Stockholm inner archipelago 1968-2015"

RC: "The abstract is too long. It can be more concise. There are some text that would go under study site description and some text that is more of a discussion." AR: We agree it can be shortened. We suggest deleting the sentence starting in the end of row 11 and the following sentence. We modify the sentence starting on row 13. The "discussion" sentences (lines 21-24) about causes of oxygen improvements will be replaced by a single sentence about oxygen consumption, P release and temperature, something like "Increasing temperatures, stimulating deep-water oxygen consumption rates in early summer, have counteracted the effects of lowered organic matter sedimentation on oxygen conditions"

RC: "The study is not put into a larger perspective, to what extent is this study interesting for the rest of the Europe or the World?" AR: We will add sentences in the introduction of the general function of estuaries as filter for nutrients. We also modify the final part of the introduction to clarify the motivation for the study (see response below) and stress the importance of studies in the Stockholm inner archipelago, which has often been used as an example in the debate about effects of P and N mitigation to coastal waters (Boesch et al. 2006, Schindler and Vallentyne 2008, Schindler et al. 2008). The latter reference is new and will be added to the reference list (Schindler et al.: Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. PNAS 105: 11254-11258, 2008). Our study also contributes to clarifying the importance of internal seasonal P cycling versus legacy P loads, and that oxygen control of P release alone is an oversimplification. We have already mentioned these problems generally in the introduction, but will modify conclusions to better link to general interest.

RC: "Are there any more studies performed in the same way, and what do they show? Weaknesses and strengths in in those and this study?" AR: We will add more general

discussion of results of some other studies, e.g. the already cited Testa and Kemp (2008) and Staehr et al. (2017). Weaknesses and strengths of previous studies in the same area are already discussed in section 4.1, but we will modify the final paragraph of the introduction to bring up the differences already here.

RC: "There are other studies of the retention of phosphorus in the same area as this study, which are mentioned in the manuscript, but what is new with this study. What is the new scientific question?" AR: This is the first temporally highly resolved dynamic box model study of the study area that follows the long-term P balance, including the period of change from high to low P load, and the first with seasonal resolution. Moreover, we link P retention to oxygen concentrations and oxygen consumption (from oxygen budget). We find lower P retention than previous studies, even periods of net P export. We find that oxygen consumption from degradation of organic matter is predominantly directly linked to P release. We also find that low oxygen can promote an additional release of P. We will clarify this in the final paragraph of the introduction. Discrepancies from other studies (mean annual P retention) are taken up in the discussion. We will also add text in the final paragraph of the introduction clarifying the scientific questions of the study. Such questions include: 1. In an estuary that has long been subject to a very high P loading, is there a long-term influence of legacy P once the load has been drastically reduced? 2. What is the current annual P retention of the area? 3. To what extent does oxygen control seasonal P release and annual P retention? Can we expect improvements in oxygen conditions to increase long-term P retention? 4. What is the effect of the temperature increase from global warming on P release?

RC: "It is not necessary to use too many abbreviations since it makes the text unnecessarily complex to read. One example is the abbreviation of the water layers, D, M, LS, US." AR: We will avoid using the water layer abbreviations in the text and write "deep water " etc, including in methods P7 L1-3. However, we still need to introduce these abbreviations for use in the equations. We will remove the abbreviations introduced on

P7 L23-31.

RC: "The Conclusion section is too long and should be more concise. It is too much of a discussion in it. The last section in the conclusion is not even discussed anywhere in the manuscript. From where was this concluded?" AR: We suggest moving most of the last two paragraphs of "Conclusions" to a new final section 4.6. We will rewrite other parts of the conclusion to make it more concise.

RC: "P1, L12. what do you mean with the "greater" Stockholm Area. However, it can be questioned if the information about the sewage treatment plants should be in the abstract at all. " AR: We agree and will delete this sentence.

RC: "P1,L18. ". . .. bloom and is exported during winter. . ..." exported to where? From the sediment to the water or to outer areas?" AR: To outer areas. Rephrased.

RC: "P1, L22-L24 The word "probably" makes it sound as it is a discussion part and not anything that is concluded." AR: We suggest removing the section about reasons for improved oxygen conditions from the abstract (lines 21-24), since this is not a main topic of the paper and needs more studies.

RC: "P1, L32 would the word "occurrence" fit better than "incidence"?" AR: We agree and will rephrase this sentence to make it clearer.

RC: "P3,L5 It is a bit unclear what you mean with small and medium towns. I would assume that it is a question of definition which can be different in different parts of the world. What do you mean?" AR: Largest "medium" towns are up to 150 000 inhabitants. Clarified.

RC: " P3, L25 Actually this is discussed in the study by Almroth-Rosell et al. (2015), full reference below." AR: Yes, this refers to the open Baltic Sea but we add this reference.

RC: "P4, L13-L14 What is the reference for the description of the area?" AR: The reference is the SMHI basin register (SMHI, 2003), used elsewhere. This reference is now added also here.

RC: " P4, L18 DIP is already defined above sections." AR: Corrected.

RC: " P4, L29 STP is also already defined in above sections. " AR: Corrected.

RC: " P6, L16 Should it be "S in Fig. 1"? " AR: Yes, clarified.

RC: "P7, L2 "LS" is not defined in the text. " AR: Defined on P5 L10. However, we will remove layer abbreviations from the running text, keeping them only for the equations.

RC: "P7, L17 K as in K in fig. 1 ? or why have K within parenthesis? " AR: Yes, clarified.

RC: "P7, L27 In PEXP-MM, what does MM mean? " AR: Mean model. The abbreviation is removed here, and defined and used in table only.

RC: " P7, L31 In PEXP-BM, BM is not defined as well. " AR: Boundary model. The abbreviation is removed here, and defined and used in tables only.

RC: "P8, L2 The net import should be defined once if it is the import-export or the opposite, but it is by definition a net result, and the word "net" should not be included as well when it is written out as P import-export. This goes for the entire manuscript." AR: Yes, corrected.

RC: " P8, L2 "closely mirrors", I am not sure that it can be seen so easy from the figure. What is the correlation coefficients? " AR: This is not a straightforward calculation since stations are often not sampled the same day. Using dates that are the same day or very close we find a linear regression coefficient $r2$ of 0.75. The mirroring will also be affected by delays, which are obscuring direct regression fits. However, we will remove the word "closely".

RC: "P9, L2 . . .. Higher in. . ... Higher than what? This can be seen also in other parts of the manuscript. Please go through and check this. " AR: Here higher after the shift 1989 than in the previous period. Clarified.

RC: "P10, L18 "closely mirrors", correlates? What is the correlation coefficients?" AR: $r2=0.97$. We add this number in the text.

RC: " P11, L1 6b, do you mean 6c?  Correct also at other places throughout the manuscript." AR: Yes, it should be 6c (6c should also be 6b in other places).

RC: "P11, L22 change July to August? " AR: We focus here on the July-October period.

RC: "P11, L23 insert water at the end or the row: surface water" AR: Modified.

RC: " P11, L29-L30 "Although . . .. . . among years." Can be seen where? " AR: Variability is indicated in fig 7c but is not shown explicitly for each year.  We add this figure reference.

RC: "P12, L19 insert "negatively" in front of "correlated". " AR: Modified.

RC: "P14, L18-L31 I am not sure what you would like to say with this paragraph. Rewrite." AR: We rephrase this paragraph and also divide it into two.  The first deals with the reasons why there is an apparent discrepancy between accumulation of sediments and low P retention (sometimes even net P release). The reasons are the problem of defining representative P burial from sediment accumulation rates and legacy P release from organic matter degradation. The second paragraph continues with further aspects on legacy P release.

RC: " P17, L1 Blomqvist et al. (2004) should be cited here, full reference below." AR: Agree. We add this reference here too.

RC: " P18, L26 ". . .. 1990 on. . ." Remove "on"." AR: Corrected.

RC: " P30, L18-L20 in c) and d) and e) it should be clarified that it is in the inner archipelago and not at a specific station." AR: Will be clarified in (d) and (e).

RC: " P30, L23-L25 Here it should be said something about the two models shown in fig. 4b." AR: Yes, added.

RC: " P30, L26 Replace the first comma with " of". " AR: Corrected.

RC: "P31, L14 Replace "yearly" with "annual" " AR: Corrected.

RC: "P31, L24 No P-value? " AR: As stated in Results (P13 L5-6), there is reason to be careful here due to interdependencies of concentrations and model results. This is why no p-value was added. Disregarding this, there is a significant linear regression, y=6.31-0.10x, r2=0.23, p<0.001 for all data. (y=6.68-0.10x, r2=0.38, p<0.0001 if normalized O2 input values <0.8 are excluded). We suggest adding p-value for the first regression within parenthesis with reference to results.

RC: "P32, L1 Replace "yearly" with "annual" " AR: Corrected.

RC: "Fig. 1 The letters showing the different stations cannot be seen properly. They are too small and the contrast with the background is too bad." AR: OK, will be modified.

RC: " Fig.3 It is hard to distinguish the dots in the legend from each other. Make larger, and change color is one suggestion. " AR: OK, will be modified.

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