

Interactive comment on “Modelling nutrient retention in the coastal zone of an eutrophic sea – a model study” by Elin Almroth-Rosell et al.

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First we would like to thank the two reviewers for their helpful and thoughtful comments. In our response we repeat the comments/questions followed by our response. We refer to page + line numbers in the original manuscript if suited.

RC-Referee comment, AR-Author reply.

Response to referee #2

RC: The model study of Almroth-Rosell et al. presents a sound model approach to improve our understanding of the nutrient retention in the archipelago of the city of Stockholm. Through a combination of different models the authors estimate the retention capacities of nitrogen and phosphorous in different basins from nutrient sources to

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the Baltic Sea. The models which are combined here and the validation of the model is logical and well done, the results may be relevant for managers. The critical aspect here is the lack of a significant increase of our mechanistic understanding of processes leading to retention or the factors impacting retention. Moreover, the processes behind the retention are not clearly described and thus it remains difficult to fully understand how the retention works in this approach. The processes described are burial and for nitrogen also the process of microbial denitrification in sediments (probably also water column, when oxygen goes to depletion). Clarification of these aspects is required and some detailed comments for improvement are given below.

AC: We thank the referee for the detailed and positive review as well as for the suggested improvements. In the revised manuscript we will describe and discuss the different retention processes in more detail and how they are affected by e.g. oxygen depletion/reoxygenation.

RC: The introduction needs more clarity and focus. The text jumps from general statements to specific Baltic Sea aspects e.g. hypoxia in the Gulf of Mexico is mentioned and next loads of nutrients to the Baltic Sea (p3 lines 8-14) or global eutrophication and loads to the Baltic Sea (p3 lines 18-22).

AC: The aim of the introduction is to put the retention question and the eutrophication problem in a global perspective. To clarify, we will reorganize the introduction to first introduce the global perspective on eutrophication and coastal nutrient retention and thereafter describe the Baltic Sea and the model study in the Stockholm archipelago that is used as an example for more detailed discussions about the processes affecting nutrient retention.

RC: I also did not understand why this example on retention (of nitrogen?) by plants is chosen (p4)?

AC: To be able to calculate the retention in an area the definition of the word need to be discussed. Plants are assimilating nutrients, why it is removed from the water mass.

This removal is however not permanent but might lead to a higher degree of burial. We thank the reviewer for pointing out the shortcoming of the implication with this example and will clarify it in the revised manuscript.

RC: Why is the expression river outlet preferred over estuary (p4 line 18)?

AC: It was not our intention to choose one expression over another. In the revised manuscript we will change the expression to estuary.

RC: The description of the archipelago (p4 lines 23-27) is very brief and general. The more detailed description follows later. This should be combined or at least the reader should be referred to the later text.

AC: The Stockholm Archipelago is the name of the area. In the revised manuscript we will refer to the study site paragraph where it is described more in detail. We will also reorganize the text and move unnecessary details about the study site from the introduction to the methods.

RC: Further below the reduction of sewage is mentioned however again without details (line 31, reduction of how much N?).

AC: We agree that more details are needed. We will include a more extensive description in the revised manuscript and also reorganize the text and move unnecessary details about the study site from the introduction to the methods.

RC: The classification is mentioned (unsatisfactory eutrophic) but what is that really?

AC: We agree that a clarification of the expression is needed. We will change the formulation in the revised manuscript and describe the environmental classification.

RC: What are high nutrient loads (p5 line 4)?

AC: We will rephrase the sentence in the revised manuscript and point out that the river Norrström supplies large nutrient loads to the inner part of the archipelago.

RC: On p.6 (lines 16-19) continue with somewhat vague site descriptions. Please add data on nutrient release over time and what the improvement of the treatment really means in concentration and load changes. Here again a combination of the text in the introduction with the study site description is would be better.

AC: We will reorganize the text to focus all the study site relevant descriptions in the methods section. We will move details from the introduction to the methods and also refer e.g. to figures of nutrients loads shown in the results section.

RC: What is the overall intention of this study – is it a retention estimate for managers, or are processes considered and their regulation by natural settings and anthropogenic impact? These are two different foci which impact the model set-up and the description of results. To me it seems that the authors mix both aspects with the results that neither aspect receives sufficient attention.

AC: The aim is to investigate the retention capacity of the coastal zone along the land to sea continuum, which is described in the aim-section in the end of the introduction. The aim is also to discuss the processes affecting the nutrient retention in the coastal areas as well as to discuss the concept of retention. We will have a closer look and rephrase/rewrite necessary parts to prevent the focus from being lost in the revised manuscript. We will therefore, as mentioned above, clarify more the processes leading to retention and the factors impacting retention.

RC: The model description is well done and clear in most cases. Minor requests for clarification are: The conversion of hydrogen sulfide into negative oxygen concentrations is sometimes used but seems not correct since it does not include the conversion of sulfate into hydrogen sulfide. What is the justification for this?

AC: We agree that this need some clarification, which will be done in the revised manuscript. The conversion of sulfate into hydrogen sulfide is included in the “negative oxygen”. Sulfate is assumed to be reduced according to the model formulations but instead of stating the amount of hydrogen sulphide produced, the term "negative

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oxygen" is used, corresponding to the amount of oxygen needed to oxidise the hydrogen sulphide. The cited reference in the manuscript will be changed to: Fonselius, S. H. (1969). Hydrography of the Baltic deep basins III.

RC: How is the amount of N and P stored in sediments calculated (p 8 line 1)?

AC: This will be better described in the revised manuscript. The sediment layer in the present model is described by one vertically integrated bulk sediment parameterization (level 3 in Soetaert et al, 2000). The organic material sinking to the sediment is divided into one nitrogen pool and one phosphorus pool described by the state variables NBT and PBT, respectively. The sediment module includes burial and aggregated process descriptions for oxygen and temperature dependent nutrient regeneration and denitrification. Reference: Soetaert, K., Middelburg, J.J., Herman, P.M.J., Buis, K., 2000. On the coupling of benthic and pelagic biogeochemical models. *Earth-Science Reviews* 51, 173–201.

RC: How is nitrification and denitrification modelled (line 8)?

AC: Nitrification and denitrification are oxygen dependent processes that occur both in the pelagic and benthic parts of the model. The processes are described in detail in the paper by Eilola et al. 2009, (referred to in the manuscript). We agree that these processes may need a more extensive description since especially the denitrification is an important retention process. But we will in this paper not repeat details about processes descriptions. Instead we want to focus on the relative impact of different processes on the nutrient retention and try to describe that even better as mentioned above.

RC: Better focus the text lines 10-21 on the critical variables for this study, burial, remineralisation – assimilation and nitrogen fixation are less important.

AC: This is a brief general description how the model works to help the reader, if not used to models, to understand that these processes are included. The paragraph does

not aim to describe the processes in details.

RC: Is the atmospheric deposition indeed significant and deserves this much attention throughout the text (see line 24)?

AC: We believe that the reader should be informed about the forcing that drives the model. Understanding the relative importance of the different drivers we consider important as well. Atmospheric deposition is one even though it is not a dominant source of nutrients in the inner archipelago. However, in the outer archipelago, which has a large area, the atmospheric input of nutrients actually is the dominant external source.

RC: Rivers hardly every supply nutrients with a N:P ratio of 16, usually the ratio is much higher (see p9 line 3-5). May be I misunderstand the calculation of the loads, but this needs conversion to true input ratios and concentration.

AC: Thank you for pointing out this shortcoming of the description. The external inorganic nutrient loads are added as DIN and DIP from the forcing as they are in the model. This will be better described in the revised manuscript. The bioavailability and the composition (dissolved or particulate) of the organic nitrogen and phosphorus loading from land are generally not known. In the present model configuration the part of organic nutrient loads following the Redfield ratio are assumed to be bioavailable. The nutrient supply that fulfils the Redfield ratio is therefore added to the detritus pool in the model while the remaining fractions of nutrient loads are treated as conservative tracers in the model. This will be better explained in the revised manuscript.

RC: The retention calculation (p11) is crucial for the manuscript. Please improve the description and explain R_{tot} better, so that equation 4 becomes clearer.

AC: Yes, thank you, we agree that this is a very important paragraph for the understanding of the study, and will improve the description in the revised manuscript.

RC: I could not understand the sentence p.12 line 22-23 about the validation of results and how representative stations are.

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AC: We agree that this sentence could be re-formulated for better understanding, which we will do in the revised manuscript. What we intend to describe is that the local conditions of stations where data are observed are very important as they can vary due to the positions of the stations. When analyzing model results and interpreting validation results it is important to be aware that the model integrates the over a large area, while observations are sampled only at one position that possibly is not representative for the average conditions.

RC: Where are the cost functions from which are mentioned (p.13 line 25)?

AC: Thank you for the remark; we will include a cross-reference to equation three in the revised manuscript.

RC: In case oxygen is not very well simulated by the model, then denitrification estimates cannot properly work in the model. How well is oxygen represented and how does that impact the results of the denitrification estimates?

AC: Thank you for the comment. The capacity of the model to simulate oxygen is acceptable at all stations except for basin "Sandöfjärden" where the vertical summer profile shows not good results. This can be seen in figure 8 (circles). However, the impact of different oxygen conditions should of course be discussed more in detail in the discussion section.

RC: In this context the retention time of the water also plays a crucial role since longer retention times should lead to decreasing oxygen concentrations in the water. It would be good to dedicate a paragraph to the linkage of these variables and discuss the model results in relation to findings at the representative stations.

AC: Thank you for the comment! Yes, we will include a discussion of this in the revised manuscript. The largest sensitivity of denitrification rates to changes in oxygen concentrations occur at concentrations below 4-5 ml/l in the model. The maximum denitrification rate is obtained at an oxygen concentration of about 1 ml/l while denitrification

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halts under anoxic conditions. We will investigate in which areas of the archipelago the model denitrification may be most sensitive to changes of the oxygen concentrations.

RC: In the present text the retention is qualitatively mentioned but quantifications are lacking (see paragraph 3.2.2).

AC: Quantification of the modelled retention are described and discussed in section 3.2.1. Quantifications of retention in other studies are shown in fig. 14 in section 3.2.2. In the revised manuscript we will in more detail discuss the different types of coastal areas and their retention capacities. We will quantify how water depth and residence time and mean bottom water oxygen concentrations affect the modelled nutrient retention.

RC: The paragraph on reduction scenarios is a pure description of model results but lacks aspects of a discussion – this would therefore need drastic shortening.

AC: We agree that the description of results are somewhat more extensive compared to the implications of the same. In the revised manuscript we will improve the discussion and better describe the implications of the reduction scenario experiment. The description of the setup of scenarios will be moved to methods and the discussions will be focused and more related also to the discussions about processes affecting retention.

RC: It would be nice to significantly reduce number of figures.

AC: Yes, we are aware that the number of figures is high. However, referee nr 1 actually wanted additional one figure. We will compromise and re-do figure nr 10. The new figure will show the total external nutrient load in the entire Stockholm archipelago and in addition the nutrient retention in the entire Stockholm Archipelago. The results which are not already discussed will be included in the discussion to improve the interpretation. The figure is separately uploaded to the discussion. We will also remove fig. nr 13, since the results are shown also in fig. 14. The text will be adjusted to fit the changes.

RC: Overall - as already mentioned above – the study would profit by a comparison of own results with other such model exercises.

AC: We have searched the scientific literature and have so far not found any similar model studies for the coastal zone. However, we will do a wider search for model exercises of nutrient budgets and retention from the literature and relate their results to our study.

RC: Although I understand why the paper was submitted to Biogeosciences it may be better placed in a model journal. As the paper stands now it does not explain the processes of nutrient retention or relate them to environmental processes (except the nutrient reduction scenario).

AC: In the revised manuscript we will overall improve the discussion of the nutrient retention processes and the impact from e.g. oxygen changes. We also think that the study has its main interests in the coastal zone as a filter, and the retention processes and not only as a modelling paper, even though we use a model as a tool. For instance, the importance of permanent relative to temporal retention needs a clarification of the processes involved that can only be quantified and explained from dynamic model results including the pools of nutrients both in the water and in the sediment as in the present study. Also the impact from changing environmental conditions such as anticipated nutrient load reductions may best be explained from model experiments. These results are already quite substantial but we embrace the criticism from the reviewer and will according to the discussions above put more emphasis on trying to explain the environmental factors that impact on the processes causing nutrient retention. We will also better discuss how our findings relate to other studies found in the literature.

Additional planned changes:

AC: We have also noticed that we in the figures use different units, which will be changed in the revised manuscript.

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