

Biogeosciences Discuss., author comment AC3  
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## Reply on RC3

Jenny Hieronymus et al.

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Author comment on "Modeling cyanobacteria life cycle dynamics and historical nitrogen fixation in the Baltic Proper" by Jenny Hieronymus et al., Biogeosciences Discuss., <https://doi.org/10.5194/bg-2021-156-AC3>, 2021

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### *Author replies in italics*

Jenny Hieronymus et al. Modeling cyanobacteria life cycle dynamics and historical nitrogen fixation in the Baltic Sea

This study incorporated a cyanobacterial life cycle model with phosphorus dependency, which improved the prediction of diazotrophic cyanobacterial blooms in the Baltic Sea. The research is quite interesting and challenging; however, I found the whole manuscript lacks a clear hypothesis, clear clarification of why phosphorus is important, and the interpretation of results is not deep enough. I could see that the authors were trying to explain the methodology as it is a complicated study, however I got lost easily as there is not a clear approach or conceptual diagram to lead the readers. I have also got a few major concerns as listed below.

*Authors: Thank you for this observation, we need to clarify our aims of the paper better in the introduction. We will revise the introduction to introduce the phosphorus dependency on an earlier stage, and also include a conceptual image of CLC (First version enclosed as New Figure 2) along with figure 2.*

*To clarify, we have for the first time included the CLC model into a 3D model for the Baltic Sea. Previously the CLC model has been used by itself (Hense and Beckman 2006; 2010) and together with a 1d water column model (Hense et al. 2013). The P dependency of cyanobacteria has not been previously included, and since phosphate is limiting nitrogen fixation in the Baltic Sea during summer (Degerholm et al. 2006, Olofsson et al. 2016 etc.) the level of P dependency needed to be evaluated to not completely overestimate the biomass of cyanobacteria. As our study demonstrated in the model experiment noP (which is reflecting the settings in the previous studies), the biomass is far above observed levels and therefore discarded as a suitable setting for the Baltic Proper. Instead we found wPlim to be closest to observations in timing and magnitude of biomass and this was chosen for the estimates (as described in lines 240-241). We will make sure this is further clarified in the revised version of the manuscript. Please see more detailed replies to these issues below.*

Introduction

From the manuscript it is not clear to me phosphorus utilization of the diazotrophic species is important in the Baltic sea, and what critical roles P plays in the dominance of the three species.

*Authors: We will clarify this early on in the revised version of the manuscript. We have some details on the topic in lines 67-71 but will extend this section to also explain the background of the model settings. The noP run is what happens when applied to the Baltic Sea if P is not limiting and no uptake or release of P by cyanobacteria occurs, with cyanobacteria biomass far above observations. Please see the extended reply to the comment above.*

## Methods

Fig. 2 seems very complicated and busy to me, and I cannot tell what processes the authors have modelled and tried to test. What is your hypothesis? To someone who is not familiar with CLC model, I am suggesting the authors making Fig. 2 easier to follow, also by adding a conceptual diagram to illustrate what life cycle really means – what are the physiological processes, timescale, input conditions and output, etc.

*Authors: We will include a CLC schematic image parallel to current figure 2 in the revised version of the manuscript (enclosed New Figure 2). We will also color code the CLC parts of the current version of Fig. 2, for example by red as the lines/arrows are in the current version as well as a new table with all the abbreviations (see enclosed New Figure 3 for a first version).*

Please also specify why CLC model needs to be modified to include P utilization. Did you mean by superior P uptake, P storage or DOP scavenging strategies?

*Authors: Phosphorus dependency has not been considered in previous versions of the CLC model but must be considered in the Baltic Sea where P is often limiting the growth of filamentous cyanobacteria (e.g., Klawonn et al. 2016, Olofsson et al. 2016; Degerholm et al. 2006). This argument for the importance of this focus will be explained better in the introduction in the revised version of the manuscript. The sensitivity run "noP" demonstrates how the CLC model reacts when there is no phosphorus limitation as well as no uptake or release of phosphorus in cyanobacteria; biomass gets far above observations and is why limitations are clearly needed for the CLC model for the Baltic Sea.*

L100 – why some of the predicted temperature were much higher? Please kindly explain the reason behind it.

*Authors: The temperature is well represented by the model. Slightly higher temperatures can be found in the upper parts of the halocline at BY15 (central Baltic sea, Fig. 10 in Meier et al., 2018). The reason is not clear but an exact reconstruction of the past is not to be expected by any model. For further details, please refer to Meier et al. (2018).*

L110 – But you could already see cyanobacterial species vary in physiology from a great many publications. I wonder if it could be better to allocate a range or different C:N:P ratios for the modelled species, maybe a sensitivity analysis could help you find out whether this ratio really matters for the simulated outcomes.

*Authors: We will think of this for the future, but for now it is too complicated. We will include a discussion around different C:N:P ratios in the revised manuscript as this may impact the ratio between biomass and nitrogen fixation.*

L125 – I am sure the internal nutrient quotas also affect the growth and life cycle transitions; however, I cannot tell if you have included internal nutrient quotas impacts. A

schematic including how processes involved in the model, alongside the methodology of this manuscript may help clarify the uncertainty here.

*Authors: Internal nutrient and energy quotas were included in the original CLC model by Hense and Beckmann (2006). In a following publication (Hense and Beckmann, 2010), they constructed a simplified model, where the internal quotas were excluded, with the aim of obtaining a model efficient enough to be included in a 3d climate model. The model that we have used is an adaptation of their simplified model but where they separated the diazotrophic and non-diazotrophic stages into a two compartment model, we have instead summed up the recruiting and the vegetative (growing but without heterocysts) stage (REC) and obtained a four compartment CLC model including pelagic akinetes (AKIW), benthic akinetes (AKIB), recruiting and vegetative non-diazotrophic cells (REC) and cells with heterocysts (HET). We will include a clearer graphic of this in the revised manuscript.*

Results and discussion

L565 – There are some extreme biomass values that were not predicted, why is that?

*Authors: The colored dots in Fig. 3 show the two daily values of simulated biomass for the different experiments. The high frequency of the model output compared to the maximum sampling frequency of once every two weeks for the observations, generates a higher probability to capture extreme highs and lows. That being said, the simulated biomass is higher in the model compared to the observations even for the best fit simulation wPlim. There could be many reasons for that such as a too high or low C:N ratio, or non optimal choices of other constants. We will, in the revised manuscript, include a table or figure showing the monthly mean values of biomass in order to more clearly see the relation between biomass and the nitrogen fixation presented in Fig. 5.*

Author reply references:

*Degerholm, J., Gundersen, K., Bergman, B., & Söderbäck, E. (2006). Phosphorus-limited growth dynamics in two Baltic Sea cyanobacteria, *Nodularia* sp. and *Aphanizomenon* sp. *FEMS Microbiology Ecology*, 58(3), 323–332. <https://doi.org/10.1111/j.1574-6941.2006.00180.x>*

*Klawonn, I., Nahar, N., Walve, J., Andersson, B., Olofsson M., Svedén, J.B., Littmann, S., Whitehouse, M.J., et al. 2016. Cell-specific nitrogen- and carbon-fixation of cyanobacteria in a temperate marine system (Baltic Sea). *Environmental Microbiology* 18: 4596–4609.*

*Meier, H. E. M., Eilola, K., Almroth-Rosell, E., Schimanke, S., Kniebusch, M., Höglund, A., Pemberton, P., Liu, Y., Väli, G., & Saraiva, S. (2018). Disentangling the impact of nutrient load and climate changes on Baltic Sea hypoxia and eutrophication since 1850. *Climate Dynamics*. <https://doi.org/https://doi.org/10.1007/s00382-018-4296-y>*

*Olofsson, M., Egardt, J., Singh, A., and Ploug, H., (2016). Inorganic phosphorus enrichments in Baltic Sea water has large effects on growth, carbon fixation, and N<sub>2</sub> fixation by *Nodularia spumigena*. *Aquatic Microbial Ecology* 77: 111–123.*

Please also note the supplement to this comment:

<https://bg.copernicus.org/preprints/bg-2021-156/bg-2021-156-AC3-supplement.pdf>