We sincerely thank the reviewer for the careful and constructive evaluation of our manuscript. We greatly appreciate the detailed and insightful comments, which have helped us improve the clarity, structure, and scientific interpretation of the manuscript. We have carefully considered all comments and have thoroughly revised the manuscript accordingly. Below, we provide our detailed responses to each comment and indicate the corresponding changes made to the manuscript.

The reviewers comments are reporduced in black

The response to reviewer in blue and the changes applied to the manuscript in red

Reviewer 2

Abstract

Comment: A modest 10% enhancement in the q10 parameter for these processes caused disproportionately big changes in nitrogen and phosphorus cycles – in the light of q10 creating a non-linear response of reaction rate, is that really a disproportionately big change?

Response: We agree that the word "disproportionately" is too strong here especially q10 generates exponential response, and replaced with "substantial changes" or "higher changes" through out the manuscript. The term "disproportionately large" is used only when referring specically to the spatially normalized coastal sensitivity quantified by Scr.

Changes to manuscript: **Line 9: "**disproportionately big**" revised to "substantial"**

Line 17: "nitrate cycle is disproportionately sensitive**" revised to "nitrate cycle is highly sensitive"**

Comment: Strong accumulation of ammonium and depletion of nitrate in the anoxic basins, indicating stronger denitrification over nitrification in warmer conditions. The manuscript does not provide a comparison between present and warmer conditions and does not present much information on denitrification.

Response: Thank you for this comment. We agree with both points and have addressed them:

- **"Warmer conditions" terminology:** Our experiments modified the q10 parameter, not related to climate warming. We replaced "warmer conditions" with "enhanced temperature sensitivity (q10)"
- **Denitrification claim:** Because we analyzed concentration pools (NH4 and NO3) rather than direct rate fluxes, we toned down our mechanistic claim to avoid over-interpreting unquantified process rates.

Changes to manuscript: The sentence revised from "strong accumulation of ammonium and depletion of nitrate in the anoxic basins, indicating stronger denitrification over nitrification in warmer conditions"

To

" with strong accumulation of ammonium and depletion of nitrate in the anoxic basins,under enhanced temperature sensitivity (q10),reflecting altered nitrogen transformation dynamics. "

Comment: Basin wide enhanced water column remineralization – does Basin refer to the entire Baltic Sea here, or to the Bothnian Bay?

Response: Here the "basin wide" represents the entire Baltic Sea and the abstract revised to reflect that

Changes to manuscript: The term "Basin wide enhanced water column remineralization also caused increased phosphate concentrations in the Bothnian Bay" revised to "Enhanced water column remineralization across the Entire Baltic Sea domain also caused increased phosphate concentrations in the Bothnian Bay,"

Comment: Disproportional role of the coast – this suggests that the coast had a larger impact than its small area would suggest, but most of the Scr values are < 1, wouldn't that point to low impact of the coast?

Response: Thank you for pointing this out. We agree that most of the Scr values are below 1, indicating that the coastal perturbation generally produces a weaker response relative to its area, However, some basin–variable combinations show Scr>1 indicating a relatively stronger coastal influence; the Bothnian Bay provides one such example that we discuss later in the manuscript To avoid implying that the coast has a disproportionately large absolute impact across all nine basins and biogeochemical variables, we have removed the term “disproportionate” from the manuscript.

Changes to manuscript: The sentence changed from “We introduced a non dimensional metric of relative coastal sensitivity to assess the disproportional role of the coast in defining the biogeochemistry of the deep Baltic basins. ”

To

“We introduced a non-dimensional metric of relative coastal sensitivity to assess the role of the coast relative to its area in defining the biogeochemistry of the deep Baltic basins.”

Comment: The Bothnian Bay displaying two to four fold stronger responses in nutrient cycles than basin wide perturbations – can you add an explanation?

Response: Thank you for the comment, and the explantion for the same is now added to the abstract.

Additional note: Our current analysis evaluates temperature sensitivity (q10) rather than directly quantifying the specific diagnostic process rates that drive the 2- to 4-fold nutrient response in the Bothnian Bay. To address this, we have strengthened our mechanistic hypothesis regarding this heightened nutrient sensitivity by incorporating robust literature support and detailed explanations in the revised discussion of our manuscript.

Changes to manuscript: The sentence changed from

“... with the Bothnian Bay displaying two to four fold stronger responses in nutrient cycles than basin wide perturbations, underscoring the disproportionate influence of coastal processes on basin biogeochemistry.”

to

“ .. with the Bothnian Bay displaying two to four fold stronger responses in nutrient cycles than the corresponding entire Baltic Sea perturbations. This underscores the disproportionate influence of coastal processes on basin biogeochemistry, driven by oxic sedimentary nutrient processing, Baltic Sea circulation and advective nutrient transport.”

Comment: Adjacent anoxic basins – the Bothnian Bay has no adjacent anoxic basins.

Response: The reviewer is correct; here, we are referring specifically to the Baltic Proper as the anoxic basin, and the advection from Baltic proper to Bothnian Sea then to Bothnian Bay

Changes to manuscript: The word “ adjacent anoxic basin” revised to “anoxic basins of the Baltic Sea”

Comment: Accurately resolving coastal processes is therefore essential to capture the coastal filter and avoid misrepresenting nutrient transport and ecosystem responses under climate change – how does this agree with the findings of the study? For most parameters Scr is <1, so the central basins seem more important than the coast.

Response: Yes, the reviewer is right. We agree that the original statement was too broad, given that the relative coastal sensitivity varies among basins and processes. As Scr > 1 occurs mainly in the Bothnian Bay, we have therefore revised the sentence to clarify that the disproportionate influence of coastal processes identified in our study is particularly evident in the Bothnian Bay, where several biogeochemical variables (NO_3, NH_4, PO_4 and phytoplankton) show high Scr values.

Changes to manuscript: The sentence changed from “Accurately resolving coastal processes is therefore essential to capture the coastal filter and avoid misrepresenting nutrient transport and ecosystem responses under climate change” to

"Accurately resolving coastal processes is there fore essential to capture the coastal filter and avoid misrepresenting nutrient transport and ecosystem responses under climate change, particularly in the Bothnian Bay, where coastal processes exert a disproportionate influence on its biogeochemistry"

Introduction

Comment: Early in the section the term "coastal" should be defined, and it should be mentioned that for this study coastal means depths < 20 m.

Response: Thank you for pointing this out. We have clarified the coastal zone definition in the Introduction by noting that most Baltic Sea coastal systems are shallow, with depths of less than 20 m, and have added the relevant references. Rather than introducing the specific model definition directly in the Introduction, we provide this broader context there and explicitly define areas shallower than 20 m as the coastal zone used in this study in the Methodology.

Changes to manuscript: In introduction Line 27 after (Holt et al., 2007), a sentence added as "In the Baltic Sea, this land–sea interface is particularly important, as most coastal regions are shallow, with depths less than 20 m (Carstensen et al., 2020),"

In methodolody a statement added as "In this study, the coastal zone is defined as model grid cells with water depths shallower than 20 m representing the shallow, sediment-influenced region where benthic and sediment–water interactions are particularly relevant (Carstensen et al., 2020; Thoms et al., 2018). "

Line 99

Comment: The experts suggest – replace by reference.

Response: The manuscript revised accordingly

Changes to manuscript: The sentence now revised from "The experts suggest that the biggest uncertainties in biogeochemical cycles. in the Baltic sea are .."

To

"The biggest uncertainties in biogeochemical cycles in the Baltic Sea are .. "

An additional reference added to the text as (Meier et al., 2019b, 2011)

Line 103

Comment: Does this apply only to coastal processes, or would that also apply to processes at depth > 20 m?

Response: We agree that temperature-driven processes in both the coastal and deeper waters influence Baltic Sea biogeochemistry. Our statement was specifically intended to emphasize the additional role of coastal processes through the coastal filter and their potential influence on nutrient export to deeper waters. We have revised the text to make this distinction explicit.

Changes to manuscript: The sentence revised from "Misrepresenting the temperature-driven coastal processes in the model can cause uncertainty in the coastal filter, hence affecting nutrient export to the deep sea and its biogeochemical cycles."

To

"Temperature driven processes in both the coastal and deeper waters influence Baltic Sea biogeochemistry; however, misrepresenting the temperature-driven processes in the coastal zone can introduce uncertainity in the coastal filter, and consequently affect nutrient export to the deep sea and its biogeochemical cycles."

Line 114

Comment: Does the paper really investigate spatial differences in temperature sensitivity? After all, q10 is changed uniformly over the model domain, with the exception for the coastal zone. In addition, it also does not discuss the changes in the coastal zone compared to …

Response: In our basin-wide experiments (E1–E4), the q10 parameter was increased uniformly by 10% throughout the Baltic Sea. In contrast, in the coastal-only experiments (C1–C4), the q10 parameter was increased by 10% only in model grid cells where the water depth is shallower than 20 m, while the default q10 value was retained in the remaining grid cells. Thus, the coastal-only experiments introduce a spatially variable q10 (ie, perturbed q10 in the coast and the default q10 in other deeper grid cells). However, the term "spatial differences in temperature sensitivity" in the original sentence does not accurately reflect the point we intended to convey, and we have therefore revised the manuscript accordingly.

Changes to manuscript: The sentence from "we investigate how spatial differences in temperature sensitivity influence .." to "we investigate how temperature sensitivity influence .."

Line 122

Comment: Does the paper really provide a classification of the deep basins? what are whole-basin processes – processes on the scale of the entire Baltic Sea or processes on the scale of each deep basin?

Response: We thank the reviewer for pointing this out. We agree that the term "classify" could imply a formal classification of the deep Baltic Sea basins, whereas our analysis instead evaluates the relative influence of coastal and Baltic Sea-wide q10 perturbations using the relative coastal sensitivity (Scr). We have therefore revised this aim to more accurately describe the scope of the analysis.

In our experiments (E1 to E4), the corresponding q10 perturbations are applied throughout the Baltic Sea. We have therefore replaced "whole-basin" with "deep Baltic Sea basin" here and throughout the manuscript

Changes to manuscript: The sentence revised from

"Classify the deep basins of the Baltic Sea based on the extent to which their biogeochemical cycles are influenced by coastal versus whole-basin processes."

to

"Assess the relative influence of coastal vs Baltic Sea wide enhanced temperature sensitivity of process rates on the biogeochemical cycles of the deep Baltic Sea basins."

Line 124

Comment: Word missing? coastal areas or deep basins?

Response: Thank you for the comment

Changes to manuscript: "coastal" revised to "coastal areas"

Model, Data and Methodology

Comment: The entire model description could be somewhat shortened and focused towards the processes relevant for the sensitivity analysis. The model description lacks dissolved organic matter, which is essential for understanding experiments C3 and E3.

Response: We agree that the original model description contained some details that were not directly relevant to the sensitivity analysis. We have therefore shortened the model description by removing details related to optical processes, particle sinking, and other processes that are not directly relevant to the sensitivity experiments. At the same time, we have clarified the role of DOM recycling and its contribution to nutrient regeneration. We have also added a reference to Section 2.1.2, where the parameterizations relevant to the sensitivity experiments are described in detail.

Changes to manuscript:

Line 135-136: the part of the sentence ", which is driven by photosynthetically active radiation (PAR)." removed

Line 136-138: the entire sentences “Photosynthesis is limited by light (Steele, 1962) and nutrients (Monod, 1949; Neumann et al., 2002). The optical model uses the chlorophyll concentration derived from the phytoplankton functional groups and the CDOM concentration (Neumann et al., 2021).” removed

Line 140: the part of the sentence “layer along with large cell phytoplankton (which accumulates in the lowest layer of water). ” removed

Line 140-141: the sentence “The particle sinking is parameterized by the Martin curve (Martin et al., 1987) to achieve a linear increase in sinking speed with depth.” removed

Line 142: The sentence “The detritus is remineralized (controlled by temperature and oxygen concentration) into ammonium” revised to “The detritus is remineralized (controlled by temperature and oxygen concentration) into phosphorous and ammonium”

Line 151: A new sentence added as follows

“ DOM recycling represents microbial degradation of dissolved organic matter, returning nutrients and carbon to inorganic pools and thereby contributing to nutrient regeneration in the water column and sediment.”

Line 153: A new sentence added after “10K increase in temperature” as follow,

“The parameterizations relevant to this study are described in section 2.1.2”

Line 142

Comment: What happens to phosphorus in detritus, is it also remineralized?

Response: Thank you for pointing out, detritus remineralized to phosphate and ammonium

Changes to manuscript: Line 142 revised from “The detritus is remineralized (controlled by temperature and oxygen concentration) into ammonium” to “The detritus is remineralized (controlled by temperature and oxygen concentration) into phosphorous and ammonium,”

Lines 143–146

Comment: Please improve the language.

Response: Sentences revised accordingly.

Changes to manuscript: The sentences revised from

“Oxygen is produced by primary production in the euphotic zone and consumed by metabolism and mineralization. Under oxic conditions, the phosphate-bound iron oxides remain in the sediment as particles, and under anoxic conditions, the dissolved phosphate is liberated from the sediment (Neumann and Schernewski, 2008).”

To

“Oxygen is produced by primary production in the euphotic zone and consumed through respiration and remineralization. Oxic conditions promote sediment phosphate retention via iron oxide binding, whereas anoxia triggers sediment phosphate release into the water column (Neumann and Schernewski,2008)”

Line 152

Comment: The description of q10 given here is “standard” Q10 = 2, which would be q10 = 0.069 K-1. Your Table 1 shows a range of q10 values used in the model, so there doesn’t seem to be a “the” q10.

Response: The reviewer is correct. The sentence “meaning a doubling of the process rate with a 10 K increase in temperature” implies a q10 value of 0.0693 K-1. However, the process-specific q10 parameters used in ERGOM are not represented by this value (except one q10 parameter in Table1). We have therefore revised the text to avoid this potentially misleading statement.

Changes to manuscript: The part of the sentence ", meaning a doubling of the process rate with a 10K increase in temperature." revised to ".. are parameterized by the processe specific q10 coefficiets (Eppley, 1972), as listed in Table 1. "

Section 2.1.2 (q10 parameterisation in ERGOM)

Comment: Please rewrite and shorten this section. Explain how Eq 1 relates to Eq 2, i.e. how Q10 and q10 relate to each other. In eq 2, reference temperature is 0 degC. Add the corresponding q10 to Figure 1, make sure that Figure 1 covers the range of q10 in Table 1.

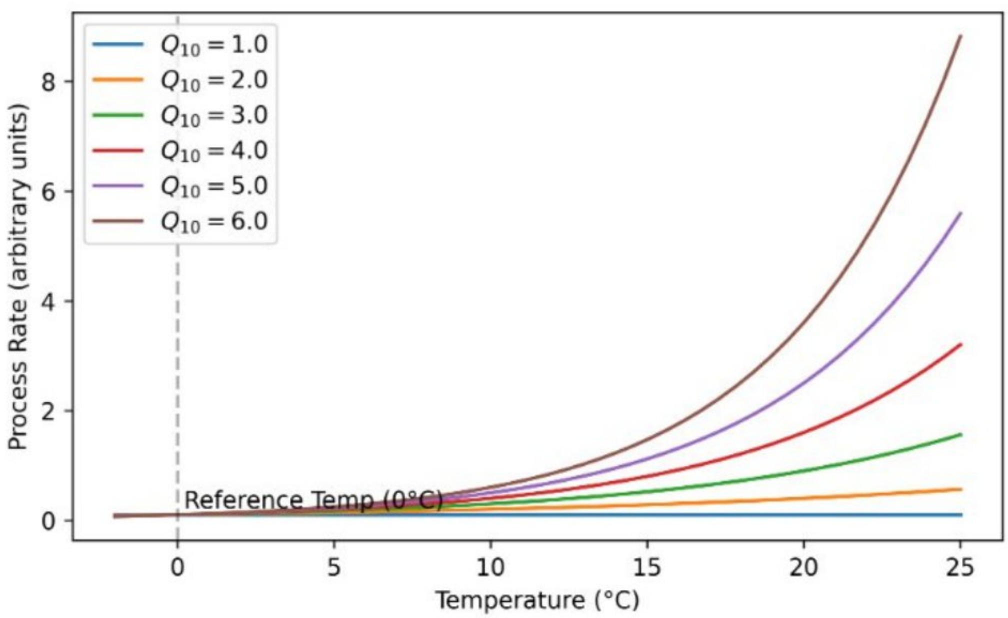
Response: We have removed the discussion of q10 parameterizations used in other models and now focus on the formulation used in ERGOM. As a result, some references that were no longer relevant have also been removed. We have also introduced an additional equation describing the relationship between the classical Q10 and the q10 parameter used in ERGOM.

Changes to manuscript: The paragraph has been shortened in the revised manuscript, and an additional equation has been added to show the relationship between Q10 and q10, as follows:

q10 = ln(Q10)/10

The Figure 1 (also given below) updated in the revised manuscript to include all q10 values used in this study

The reference temperature of 0°C has been added to the description of Equation 2.



The caption of Figure 1 changed to "Figure 1. Effect of Q10 parameter on the reaction rate across temperatures. The curves represent reaction rates for Q10 values of 1.0, 2.0, 3.0, 4.0, 5.0 and 6.0, showing how reaction rates increase exponentially with temperature relative to the reference temperature of 0°C, based on the classical Q10 formulation."

Lines 180–181

Comment: You already present this information in Table 1.

Response: We have removed this redundant statement from the manuscript.

Changes to manuscript: The sentence "In ERGOM, the detritus recycling in sediment, detritus recycling in the water column, DOC recycling, and nitrification are formulated based on the q10 parameterization." revised to "The process specific q10 values used in ERGOM are summarized in Table 1."

Lines 201–204

Comment: Please provide the basic equations for the four processes in Table 1, and include basic equations for N dynamics, including also denitrification since it is discussed in the paper.

Response: : We agree that providing the basic equations would clarify how the four temperature-sensitive processes are represented in the model and how they influence the nutrient dynamics discussed in the manuscript. We have therefore added simplified governing equations for the four (q10)-controlled processes and for the main NH4, NO3, and PO4 dynamics. The nutrient equations summarize the principal source and sink terms implemented in ERGOM, including organic-matter remineralization, phytoplankton and zooplankton respiration, nutrient assimilation, nitrification, denitrification, coupled nitrification–denitrification, sedimentary phosphate release under anoxic conditions, and phosphate retention under oxic conditions. The equations are written in a grouped form to present the main biogeochemical pathways without reproducing the full set of individual stoichiometric reactions and functional-group-specific terms in the ERGOM formulation and for more details readers are then redirected to Neumann et al., 2022 in the revised manuscript

Changes to manuscript: The model description has been expanded to include the basic formulations of the four temperature-sensitive biogeochemical processes listed in Table 1, together with simplified representations of the main NH_4, NO_3, and PO_4 dynamics. The revised description also explicitly includes nitrification, denitrification, and coupled nitrification–denitrification.
The simplified basic nutrient equations for N and P are provided in Section 2.1.1.
The equations describing the q10 formulation for the four temperature-sensitive processes are provided in Section 2.1.2.

Section 2.2.1 (Details of sensitivity analysis)

Comment: This paragraph should include how VE and VC are calculated – I think you bring that up only very late in line 266. Please describe clearly how you generate V for the model rectangles in Fig. 2. Was V calculated based on the entire 70-year model run or only on selected years?

Response: We have substantially rewritten Section 2.2.1 for clarity, also incorporating the suggestions raised by Reviewer 1. In the revised section, we now clearly describe how (V), (V_0), (V_E), and (V_C) are calculated. Specifically, the model state variables are vertically integrated throughout the water column, annually averaged over 1989–2019, and spatially averaged within each of the nine deep Baltic Sea basins shown in Figure 2. We also clarify the distinction between the basin-wide and coastal-only sensitivity experiments and the calculation of (S), (Sc), and (Scr).

Changes to manuscript:

(1) A new lines added to the manuscript as " In this study, V represents model state variables such as Nitrate (NO3), Ammonium (NH4), Phosphate (PO4), Dissolved Oxygen (O2) and phytoplankton biomass (phyto). To estimate V, the model state variables were vertically integrated throughout the water column, averaged annually over the period 1989–2019, and then spatially averaged within each of the nine deep Baltic Sea basins shown in Figure 2. In Equation 3, V0 and VE represent the value of V in the baseline and the sensitivity simulation respectively."

(2) Another line added as "The resulting model state variable (V) from these simulations in the nine deep Baltic Sea basins is denoted as Vc ." just above Equation 4

(3) A line added at Line 193 after "Baltic Sea accurately" as follows

"For the sensitivity analysis, the period 1989–2019 was selected from the 70-year simulation period."

(4) The sentence "Here, hydrogen sulphide (H_2S) is considered as a negative O_2 concentration ($2H_2S=-O_2$)." in line 264-265 moved to the beginning of section 2.2.1

(5) Removed the sentence "We assume that the biogeochemical variables are quantified outside the coastal zone (in the nine rectangles shown in Figure 2). " from line 265-266

Comment: In your equations, subscripts E and C only seem to denote the different simulations. It would make the text clearer if you presented only one general equation.

Response: Thank you for the suggestion

Changes to manuscript: The equations for S and Sc have now been represented by a single general equation as follows:

$S\_X = (V\_X - V0)/V0 * 100$

- X=E for the basin-wide Baltic Sea experiment.
- X=C for the coastal-only experiment.

Comment: It also seems that no selected stations (line 222) are involved and since only q10 is changed, it is not necessary to involve an abbreviation for parameter P and the change deltaP.

Response: The reference to a "selected station" was not appropriate because the state variables used in our sensitivity analysis are basin-scale spatial averages rather than station-based values. We have therefore removed the reference to selected stations and clarified how the state variables are calculated. In addition we also removed the generic parameter (P) and perturbation (\Delta P) notation as per the suggestion

Changes to manuscript: The sentence "For a model state variable V of interest (such as water column nitrate concentration in a selected station), the percentage sensitivity to a change in parameter P (i.e. ΔP) can then be defined as" removed from the manuscript

In addition "model parameter P" is replaced with "q10 parameter" through out the manuscript

Lines 225–238

Comment: Shorten, check for correctness, for example the rate change to a 10% change in q10 does not depend on whether the temperature is given in Celsius or Kelvin, since it only depends on the difference between T and Tref.

Response: The statements regarding the dependence on the temperature scale and the formulation of the process equations have therefore been removed. We have also shortened and revised Section 2.2.1 to improve clarity and avoid unnecessary discussion.

Changes to manuscript: The sentence "In our example, it would depend on whether we give the temperature in Celsius or Kelvin. However, different but mathematically identical ways of writing the process equations will affect the value of S, such as using the square of a parameter rather than the parameter itself, or even logarithmic parameters. Therefore, a quantitative comparison between the S values for different parameters is not meaningful unless the exact formulation of the model equations is taken into account in the interpretation" removed from the text

In addition the entire section 2.2.1 shortened and rewritten for clarity.

Lines 239–250

Comment: Introducing the normalization according to the area ratio actually represents the methodology that you promised to introduce in line 220. It looks like that you are testing this methodology in your paper. Therefore lines 239–245 sound speculative and not really relevant to the paper.

Response: Since the relative coastal sensitivity metric is a central methodological component of this study, we haveremoved the speculative discussion and revised Section 2.2.1 to introduce the methodology directly and more clearly.

Changes to manuscript: The lines 239-245 removed from the revised manuscript.

Section 2.2.1 has been rewritten to directly describe the calculation of coastal sensitivity (Sc), its comparison with the entire Baltic Sea-domain sensitivity (S), and the subsequent normalization by the coastal-to-total area ratio to obtain the relative coastal sensitivity (Scr).

Lines 247–250
Comment: Please give the ratio of Ac/A for the Baltic Sea (it seems that you used 0.224?).

Response: The ration Ac/A =0.2884

Changes to manuscript: "Ac/A (0.2884)" added to the manuscript.

Line 249
Comment: factor Ac/A.

Response: Thank you for pointing the error

Changes to manuscript: The wording "factor Ac" corrected to "factor Ac/A"

Lines 252–255
Comment: Please improve the language. And I don't quite understand from the text how you classified Scr. Scr=0 means that the parameter change has no impact on your non-coastal test areas. Since you didn't investigate the impacts on the coastal zone, you cannot conclude that the effect remained localized. But 0 < Scr < 1 would mean that the response to a coastal zone parameter change only is weaker than expected from the ratio of coastal to entire Baltic Sea area, > 1 that the response is stronger? Please explain clearly what different values of Scr imply. How do negative Scr fit in that context?

Response: Indeed the discussion of the S_{cr} categories was not too clear. We have revised the text to explicitly clarify that the metric (Scr) describes the response of the deep Baltic Sea basin ecosystem to parameter perturbations applied either only within the coastal zone or across the entire Baltic Sea domain. We now explain that (Scr=0) indicates that coastal parameter perturbations do not influence the corresponding deep basin ecosystem response, whereas (Scr ~ 1) indicates that the deep basin responds similarly to coastal-only and entire Baltic Sea domain parameter perturbations. We have also added interpretations for (Scr>1) and negative (Scr) values to clarify cases where coastal perturbations produce stronger or opposite-sign responses compared with perturbations applied across the entire Baltic Sea domain.

Changes to manuscript: The interpretation of Scr values (zero, close to one, greater than one, negative) was rewritten with explicit reference to the deep Baltic Sea basin responses, including a mechanistic example for negative Scr. As also requested by reviewer 1 (Lines 254–255, 258–260).

The entire paragraph rewritten for clarity as follows

"A value of Scr equal to zero indicates that perturbations applied to the parameter within the coastal zone do not influence the ecosystem functioning of the corresponding deep Baltic Sea basin. A value of Scr close to 1 means that the deep Baltic sea basin responds in the same way to the parameter perturbations both in the coastal zone and the entire Baltic Sea. So, in such cases, using identical parameter values for both coastal and offshore regions will not make substantial differences in deep Baltic Sea ecosystem responses. If the value of Scr is larger than one, this means that the process in the coastal zone requires further constraint, since the deeper basins reacts with a higher sensitivity to changes we make in the parameterization here. If the value of Scr is substantially negative, it indicates that the coastal-only and full-domain perturbation experiments produce responses of opposite sign in the corresponding deep Baltic Sea basin."

Lines 255–260
Comment: This might fit better into the discussion section. If you are proposing using Scr to identify sensitive processes in the coastal zone, then you should come back in the results and discussion section of the paper and show that this approach is reasonable. For the method section of the paper the content is too speculative.

Response: The "speculative content" was meant as a motivation to explain why we are looking at the differences between coastal and offshore parameter sensitivity. But we agree that it goes beyond a method description and keep it more general now.

Changes to manuscript: We removed the sentence "If the value of S_{cr} is larger than one, this means that the process in the coastal zone requires further constraint, since the deeper basins reacts with a higher sensitivity to changes we make in the parameterization here." After the generic sentence "This methodology helps us determine which model parameters should be explicitly constrained in the coastal region to reduce model biases", which we kept, we appended ", as will be explained in the Discussion section of the manuscript".

Line 260

Comment: Scr values are masked when abs(S)<1% – please correct the caption to Figure 5 accordingly.

Response: Thanks for spotting these details!

Changes to manuscript: changed from "below 1" to "below 1 %"

Results

Comment: In the results section I miss a presentation by how much a 10% increase in q10 could potentially increase process rates, given the base q10 values in the model and the ambient temperatures in the basins for which the results are presented. This is essential to understand why changes in q10 have a large impact on some processes and little effect on others.

Response: Good suggestion.

Changes to manuscript: We append two columns to Table 1 (which was anyway extended), giving the relative increase of the process rates at 5°C and 20°C for information.

Section 3.1 (basin-wide)

Comment: What do you mean by basin-wide? Can you find precise wording throughout the paper when you are talking about the different basins you present in your model results (Fig. 3 – 5) in contrast to changes that are applied to the entire model domain?

Response: Here the term "basin-wide" means the entire Baltic Sea not the individual basins shown in Figure 2

Changes to manuscript: Throughout the manuscript the term "basin-wide" replaced as follows;

The "basin-wide" replaced with more clear wording as follows

Line7: the sentence "..processes by increasing the q10 parameter both basin wide and selectively in the coastal zone of the Baltic Sea" have been revised to "We conducted two sets of sensitivity experiments to examine the effect of enhancing the temperature driven biogeochemical processes by increasing the q10 parameters across the entire Baltic Sea domain and selectively within the coastal zone. "

Line13-14: the sentence "Basin wide enhanced water column remineralization also caused increased phosphate concentrations in the Bothnian Bay" have been revised to "Enhanced water column remineralization across the Entire Baltic Sea domain also caused increased phosphate concentrations in the Bothnian Bay"

Line 17-18: the sentence "The analysis shows that the nitrate cycle is disproportionately sensitive to coastal sediment recycling, with the Bothnian Bay displaying two to four fold stronger responses in nutrient cycles than basin wide perturbations" have been revised to "The analysis shows that the nitrate cycle is disproportionately sensitive to coastal sediment recycling, with the Bothnian Bay displaying two to four fold stronger responses in nutrient cycles than the corresponding entire Baltic Sea perturbations"

Line 21-22: the sentence "In contrast, basin wide enhancement releases .." have been revised to "In contrast, Enhancement across the entire Baltic Sea domain releases"

Line 302: the sentence changed from “Following the basin wide assessment of enhanced temperature sensitivity on biogeochemical variables, ” to “Following the basin wide assessment of enhanced temperature sensitivity on biogeochemical variables, (hereafter "basin wide" refers to sensitivity experiments in which q10 parameters are perturbed across the entire Baltic Sea domain), ”

Comment: Southern, northern, western: please make sure that these terms are used consistently throughout the paper.

Response: Thank you for looking in detail and the words are revised to be consistent throughout the manuscript

Changes to manuscript:

Line 288: the wording revised from “NO3 increased/decreased in the northern basins (Arkona and Bornholm)/Gotland Basins,” to “NO3 increased/decreased in the southern/northern basins (Arkona and Bornholm)/Gotland Basins,”

Line 280: “Northern” revised to “northern”

In Figure 2 caption: “Western Gotland Basin”,” Eastern Gotland Basin” and “Northern Gotland Basin” revised to “western Gotland Basin”, “eastern Gotland Basin” and “northern Gotland basin” respectively.

The basin titles on Figure 3, 4 and 5 also updated accordingly.

Line 531: “(Western, Eastern, and Northern)” revised to “western, eastern, and northern”

Line 296: “Western” revised to “western”

Lines 273–274

Comment: This should be explained in the method section and removed here.

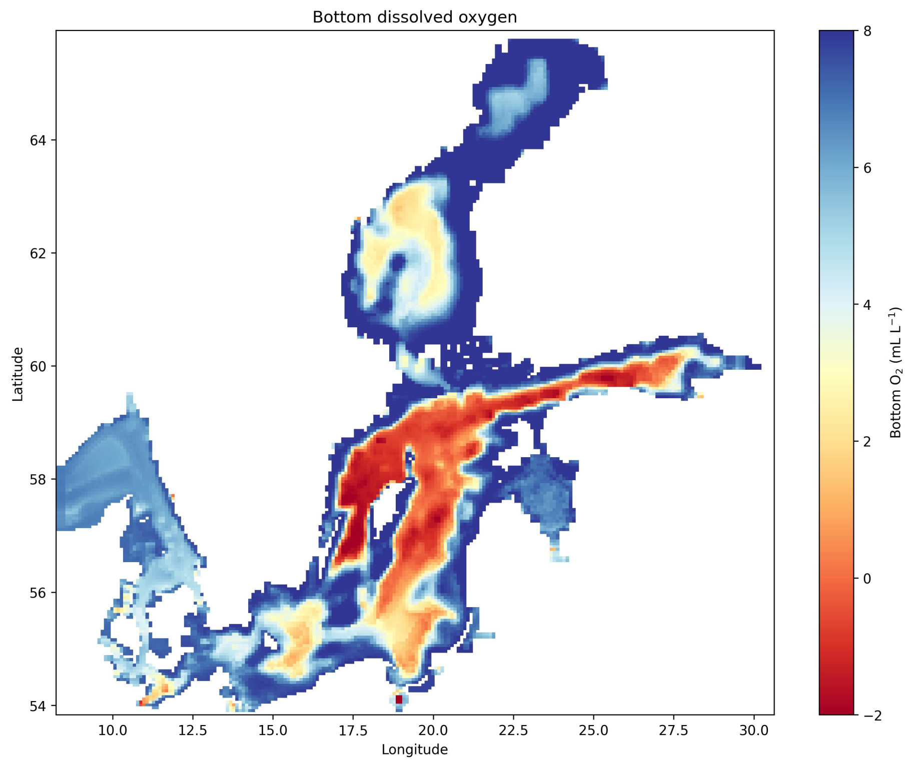
Response: Indeed this works better in the methods section.

Changes to manuscript: We removed the sentence “The targeted variables are depth integrated from surface to deep layer, basin averaged, and year averaged”. We rather append at the end of Section 2.2: “Five variables were chosen to study the impact: Total N in phytoplankton, nitrate, phosphate, ammonium, and dissolved oxygen. Their concentrations were vertically integrated, then horizontally averaged for each of the nine boxes shown in Figure 2, and finally averaged in time. So we get a kind of average concentration for each basin’s central area.”

Comment: Oxic basins: Please add a statement that describes which basins were oxic in your model simulation. How were oxygen conditions in the Gulf of Finland, Bornholm Basin and Arkona Basin?

Response: We have clarified the oxygen conditions of the basins referred to as oxic and anoxic in the manuscript. Based on the simulated annual-mean bottom oxygen concentrations (ml/l), the Arkona Basin, Bornholm Basin, Bothnian Sea, and Bothnian Bay remained well above the commonly used hypoxic threshold of 2 mL L^{-1} (HELCOM) and were therefore considered as oxic in our analysis. The Gulf of Finland exhibits more variable oxygen conditions and is therefore not classified as uniformly oxic. The Gotland Basins (northern, western, and eastern) show severe oxygen depletion, with H_2S production, and are therefore referred to as anoxic basins in the manuscript. We have added the simulated bottom oxygen distribution (after accounting H2S as negative oxygen) as a Supplementary Figure to provide a spatial overview of oxygen conditions across the Baltic Sea and to support the discussion of oxic and anoxic processes in the manuscript.

Changes to manuscript: A concise statement clarifying the oxygen conditions of the investigated basins has been added to the manuscript. In addition, a supplementary figure (also shown below) showing the simulated annual-mean bottom oxygen concentrations (represents the oxygen-equivalent concentration, calculated by accounting for the oxygen demand associated with H_2S i.e., O_2 equivalent = $O_2 - 2H_2S$). mL L^{-1}) for the period 1989–2019 has been added to provide spatial context for the classification of oxic and anoxic basins.



Line 283 (significant)

<u>Comment:</u> The accumulation of NH4 is observed with a significant decline in water column NO3 -> please don't use the term significant outside a statistical context (applies to entire paper). Also, to which basins does that apply? Do you also see basins where both NO3 and NH4 increase or where both decline? Is there a difference between the response to sediment or detritus recycling?

<u>Response:</u>

<u>(1)</u> You are right that the "significant" was used without referring to significance tests in several locations in the manuscript.As you noticed in your next comment, the other points were captured later.

(2) The statement "The accumulation of NH_4 is observed with a significant decline in water-column NO_3" refers specifically to the Northern Gotland Basin. We have revised the sentence for clarity and removed the term "significant."

(3) NH_4 and NO_3 increase together in the E2_DetWat experiment in all basins except the Gotland Basins (Northern, Western, and Eastern Gotland Basins). This basin-specific response is now discussed in the revised manuscript

(4) A simultaneous decline in both NH_4 and NO_3 is observed in the Bothnian Bay in the E1_DetSed experiment. We have clarified these contrasting basin-specific responses in the revised manuscript.

(5) We have also clarified the differences between the N responses to sediment detritus recycling (E1_DetSed) and water-column detritus recycling (E2_DetWat),

<u>Changes to manuscript:</u> We removed "(but still significant)" here, "and are insignificant" in Line 326, "significant(ly)" in Line 447, 545, 594, "and insignificant" in Line 485. We replaced "(in)significant" by "substantial" in

Lines 10, 32, 335, 375,437, by "a disproportionately large fraction" in line 30, with "nonlinear" in line 267, with "an opposing" in Line 282, with "highest" in Line 291, "negligible" in Line 311, "clear(ly)" in 386, 430, 440, 503, 543, "low" in Line 439, 488, "unimportant" in Line 522, "large" in Line 608.

The sentence describing the NH_4 accumulation and NO_3 decline has been revised to specify the Northern Gotland Basin and to remove the term "significant." We have also added clarification of the basin-specific NH_4 and NO_3 responses under E1_DetSed and E2_DetWat, including cases where both variables increase or decrease.

Comment: I realize that you present these aspects in lines 286–291. Can you improve the structure of the nutrient result section? Would it be easier to structure the nutrient results by the four q10 experiments?

Response: Thank you for the suggestion. We have structured the section by variables and processes in Section 3.1 and 3.2, then using our newly invented metric in 3.3, and looking at specific effects in 3.4. We prefer to keep the existing structure, as otherwise, the same logic (variables and processes, relative importance of the coast, mechanistic links) would have to be repeated for each of the four experiments. Both options have pros and cons, but we would like to stick to the existing one.

Changes to manuscript: No changes to manuscript.

Line 286

Comment: E1 addresses sediment mineralization rate, not detritus mineralization rate.

Response: This mixed response is evident in E1_DetSed and E2_DetWat. We intended to clarify that, in E1_DetSed, the **S** values for NO_3 are positive in the Arkona Basin, Bornholm Basin, and Bothnian Bay, whereas all other basins show negative **S** values.
Similarly, in E2_DetWat, all basins show negative **S** values except the Eastern Gotland Basin, Northern Gotland Basin, and Western Gotland Basin.
Here this mixed positive and negative responses are visible in both E1_DetSed and E2_DetWat

Changes to manuscript: The sentence changed from

"Nitrate (NO3) exhibits mixed responses to enhanced detritus recycling rates, showing a pronounced negative sensitivity in E1 for the Gotland Basin (-6 to -11%) as well as in the Gulf of Riga, Gulf of Finland, and Bothnian Bay (-2 to -3%)."

To

"Nitrate (NO_3) exhibits mixed responses to enhanced detritus recycling rates in both the sediment and water column. In E1_DetSed, NO_3 shows pronounced negative sensitivity in the Gotland Basins, with S values ranging from −6% to −11% in the Western, Eastern, and Northern Gotland Basins, while weaker negative sensitivities (−2% to −3%) are observed in the Gulf of Riga, Gulf of Finland, and Bothnian Bay. In contrast, all other basins show positive sensitivity. In E2_DetWat, NO_3 shows positive sensitivity in the southern and northern basins (Arkona, Bornholm, Bothnian Sea, and Bothnian Bay) and negative sensitivity in the Northern, Western, and Eastern Gotland Basins, which is consistent with the spatial pattern observed in E1_DetSed (Figure 3)."

See also the reviewer 1 comments and response under Lines 286-287: "Is this in general ..."

Line 296

Comment: The Western Gotland Basin sticks out with an oxygen decline.

Response: We agree that the stronger oxygen decline in the Western Gotland Basin warrants clarification. Our sensitivity experiments were not specifically designed to diagnose the processes responsible for the basin-specific oxygen response. However, previous modelling studies have shown that changes in nutrient inputs can substantially affect oxygen sources and sinks in the central Baltic Sea, with pronounced oxygenation responses in the Northern and Western Gotland Basins under reduced nutrient loads (Naumov et al., 2023). We have added this reference to provide context for the stronger oxygen response observed in the Western Gotland Basin in our experiments. We also clarify that the specific mechanisms responsible for this basin-specific response were not explicitly investigated in the present study.

Changes to manuscript:

Line 297 after ".. In E1 and E2" new sentences added as below:

"Previous modelling studies have shown that changes in nutrient inputs can substantially affect oxygen sources and sinks in the central Baltic Sea, with pronounced responses under reduced nutrient loads in the northern and western Gotland Basins (Naumov et al., 2023). This provides relevant context for the stronger oxygen response observed in the western Gotland Basin in our sensitivity experiments (E1_DetSed and E2_DetWat), although the mechanisms responsible for this basin-specific response were not explicitly investigated here."

A new reference added to the manuscript as follows,

Naumov, L., Meier, H. M., & Neumann, T. (2023). Dynamics of oxygen sources and sinks in the Baltic Sea under different nutrient inputs. *Frontiers in Marine Science, 10,* 1233324.

Line 304 (coastal zone definition)

Comment: Coastal zone should be defined only once, in the methods section.

Response: Thankyou for pointing out and the definition of coastal zone is now only present in the method section

Changes to manuscript: The coastal zone (depths shallower than 20 m) was defined in the Methods section (Section 2.2.1), consistent with Reviewer 1's request (Comment on Line 234) to provide the coastal zone definition in the Methods section. Accordingly, the definition has been removed from the Results section.

In the method section 2.1.1 following sentences added

"In this study, the coastal zone is defined as model grid cells with water depths shallower than 20 m representing the shallow, sediment-influenced region where benthic and sediment–water interactions are particularly relevant (Thoms et al., 2018). and have an area of 9.976 × 10^4km2, a small fraction of the total area of the Baltic Sea (3.459 × 10^5 km2)"

Removed "(shaded region in Figure 2)" from line 304

Line 304 (weak)

Comment: How is "weak" in weak responses defined? Given your scaling factor Ac/A, you expect the response in the coastal zone experiment to be only about 22% of the response for the entire model domain. In the Baltic wide experiments you describe effects in the 2–3% range, that would correspond to about 0.5–0.7% in the coastal experiment, whereas here you mention only effects >3% for your coastal experiment.

Response: The reviewer is right that the term "weak" was not appropriate without considering the spatial extent of the coastal perturbation. The area scaling factor used in our analysis is Ac/A=0.2884, which has now been added to the revised Methods section (Section 2.1.1). Under the assumption that the coastal region produces a response proportional to its spatial extent, the expected coastal response would therefore be approximately 28.8% of the corresponding response in the basin-wide experiment (ie Sc = 0.2884 . S). Thus, a 2–3% response in the basin-wide experiment would correspond to an expected coastal response of approximately 0.57–0.86%.

In the submitted manuscript, we focused primarily on the magnitude of the responses in the coastal experiments (relative to the variable in base simulation) and used the term "weak" without considering this area-proportional expectation. We agree that this is not appropriate, because the main objective of our analysis is to assess whether the influence of coastal perturbations is proportional to the spatial extent of the perturbed coastal region. We have therefore revised the entire section to remove this qualitative classification and explicitly introduce the 28.8% area-proportional expectation. The responses are then quantified using the Scr metric in the following section (3.3).

Changes to manuscript: The sentence "All the targeted variables show weak responses to enhanced process rates except NH4 (a positive sensitivity 3% in the western and northern Gotland basin, and the Gulf of Finland in C2" removed from the revised manuscript.

The entire paragraph rewritten to include "Among the five biogeochemical variables considered, NH4 exhibits the highest coastal sensitivities (Sc) in the C2_DetWat experiment, with values of approximately 3% in the western and northern Gotland basin, and the Gulf of Finland (Figure 4). The corresponding basin-wide sensitivities (S) for NH4 in the western and northern Gotland Basin and the Gulf of Finland are 36.29%, 43.79%, and 24.04%, respectively (Figure 3), corresponding to expected coastal sensitivities of 10.47%, 12.63%, and 6.94%, respectively, if the basin-wide response scaled proportionally with the coastal area fraction (i.e., 28.84). The observed Sc of approximately 3% (for NH4) is therefore substantially lower than these expected values. Conversely, the smaller Sc values of the other biogeochemical variables (NO3, NH4, PO4 and phyto in C1_DetSed and C2_DetWat, Figure 4) do not necessarily indicate weaker coastal influences. This is particularly evident in the Bothnian Bay for C1_DetSed and C2_DetWat, where relatively small Sc values correspond to a strong coastal influence after accounting for the spatial extent of the perturbed region, as discussed in Section 3.3."

Would it be more informative to present where the direction of change is the same as in the Baltic-wide experiment?

Response: Thank you for the suggestion, The manuscript revised accordingly

Changes to manuscript: A new sentence added to the section 3.2 as "The coastal q10 perturbations produce both positive and negative responses among the biogeochemical variables and deep Baltic Sea basins (Figure 4). The direction of the coastal response (positive or negative) is consistent with that of the corresponding basin-wide experiment for most of the biogeochemical variables and basins (Figures 3 and 4), with the main exceptions occurring for NH4 and NO3 in the Arkona Basin and for PO4 and phytoplankton in the Bothnian Bay in E1_DetSed (Figure 3, top-left and bottom-right panels) and C1_DetSed (Figure 4, top-left and bottom-right panels)."

Lines 308–316

Comment: This can be shortened/removed, the area and depth values should be moved to the method section, the weaker expected response is a recap from the method section.

Response: Thank you for the suggestion.

Changes to manuscript: We have removed the entire paragraph from the Results section and added the depth information to the Methods section.

Section 3.3 / Lines 318–319

Comment: Is the "clear influences of coastal parameterizations" the exception or the rule here? There are 85 Scr values presented in Figure 5, but only 6 are > 1. For 10 cases, Scr is negative, i.e. S and Sc have opposite signs.

Response: Thank you for the comment and the reviewer is correct, here the "clear influence of coastal parameterizations" is the exception.

Changes to manuscript: the phrase "clear influence" replaced with "potential influence"

New sentences added as " In particular, coastal detritus recycling in sediments and the water column produces the strongest relative coastal responses for NH4, NO3, PO4, and phyto, with the largest impacts occurring in the offshore waters of the Bothnian Bay (Figure 5, bottom-right panel)." at line 319 after ".. Various deep Basins of the Baltic Sea"

Lines 328–351

Comment: It is important and interesting to point out differences and also opposing responses of variables in S and Sc, but much of the interpretation presented here is speculative, needs to be analyzed properly and belongs into the discussion section of the paper. Further, much of the information presented is repeated in section 3.4. It would improve the flow of the paper to present the patterns in S and Sc only in Section 3.4.

Response: Thank you for this important suggestion. We agree that some of the interpretation in the original Section 3.3 extended beyond the direct results of Scr and overlapped with the contents of section 3.4. We have therefore revised Section 3.3 to focus on the quantitative patterns in Scr, The comparison of basin-wide and coastal responses, including differences and opposing response directions in S and Sc, is now addressed in Section 3.4.

Changes to manuscript: Section 3.3 has been substantially revised throughout. Section 3.4 has also been revised to consolidate the comparison of S and Sc and avoid repetition.

Section 3.4

Comment: I am not familiar with the units mol.m/kg used in Figs 5–9. Please explain or change to a more conventional unit.

Response: The variables analyzed in this study are depth-integrated water column quantities. Therefore, the resulting units represent areal inventories. To make the results more comparable and easier to interpret, we have converted the units into more conventional depth-integrated forms commonly used for biogeochemical analyses. And all the figures now redrawn with new units

Changes to manuscript: The units in the figure captions were revised to conventional area-integrated units, e.g. Figure 6 nitrate to "µmol N m^-2", Figure 8 phosphate to "µmol P m^-2", Figure 9 oxygen to "µmol O m^-2", and Figure 10 phytoplankton to "mg C m^-2" (replacing "mol.m/kg"). Accordingly, all corresponding values and units in the text have been updated, and Figures 6–10 have been redrawn with the revised units and updated values.

Also see the response of reviewer 1 line 372

Fig. 9

Comment: It should be nitrate in the caption – (the caption should refer to the correct variable).

Response: Thank you for pointing out

Changes to manuscript: The Figure 9 caption corrected from "nitrate" to "oxygen" concentration (O2). As also requested by reviewer 1 (Figure 9).

Discussion

Comment: The discussion needs to be structured more clearly. It needs to be shortened, since large parts reiterate material presented in the results and method section. Main points that are discussed (and might help in restructuring) are: sensitivity towards sediment detritus mineralization (impact on N and P, differences between oxic and anoxic basins) – this has been found in many other studies and needs to be put into context of the literature and shortened; using relative coastal sensitivity as a measure to identify critical coastal processes – this is an interesting aspect postulated as a new method; diverging patterns in coastal and Baltic-wide experiments, role of coastal FeP formation, masking of coastal processes by transport from deep basins – this should be discussed in greater detail, involving more areas than the Bothnian Sea.

Response: Thank you for this helpful suggestion. We agree that the Discussion benefited from a clearer structure.We have therefore substantially revised and shortened the Discussion

We now focus the first part of the Discussion on the contrasting responses of NH_4 and NO_3 to enhanced remineralization, with particular emphasis on the differences between oxygenated and oxygen-depleted basins. We have also added relevant literature to place these findings in the context of previous literature

We have revised the discussion of Scr to more clearly explain its purpose and interpretation as a metric for identifying coastal processes that may have a disproportionately large or mechanistically different influence on deep-basin biogeochemistry. We emphasize that this metric provides a framework for identifying coastal parameterizations that may warrant particular attention in model calibration.

We have expanded the discussion of the contrasting responses between the coastal-only and Baltic Sea-wide experiments. In particular, we discuss the negative and high Scr responses in the Arkona Basin and Bothnian Bay and consider how differences in sediment redox conditions and the retention of phosphorus under oxic conditions may contribute to the contrasting responses.

We have expanded the discussion of the contrasting PO_4 response in the Bothnian Bay to consider the potential role of Fe-bound phosphorus retention in oxic coastal sediments and the contribution of phosphorus transported from other Baltic basins during the Baltic Sea-wide perturbation. We explicitly frame these mechanisms as a plausible hypothesis supported by previous observations and literature, rather than as processes directly quantified by our sensitivity experiments.

Finally, we now compare the Bothnian Bay response with the Gulf of Finland, where Scr is positive, indicating that the coastal-only and Baltic Sea-wide perturbations do not produce the same contrasting response observed in the Bothnian Bay. This comparison helps clarify that the proposed mechanism is basin-specific and depends on regional environmental conditions and the interaction between coastal retention processes and basin-scale nutrient transport.

Changes to manuscript: Lines 506 to 528 removed from the manuscript as it was repetation from the methodology

The Discussion section (Section 4) has been substantially reorganized and shortened to reduce repetition of the Results and to provide a clearer focus on the main findings, including oxic–anoxic differences, sediment versus water-column remineralization, the interpretation of Scr, and the contrasting coastal-only and Baltic Sea-wide responses.

Comment: The Summary and Conclusion section states the high sensitivity of some processes towards a 10% q10 change (line 580). To explain the high sensitivity of some processes, the discussion section should address the different impact of the 10% q10 change on modelled rates, considering the role of base q10 and ambient temperature.

Response: Reviewer is right, We thank the reviewer for this helpful comment. We have clarified in the Discussion that the magnitude of the change in process rates following a 10% increase in q10 depends on both the process-specific baseline q10 value and ambient temperature (This information is also added to Table 1). Thus, the same relative q10 perturbation can produce different changes in process rates among basins due to temperature differences and among processes due to their different baseline q10 values.

Changes to manuscript:

Follwong text added to the discussion "The magnitude of the change in process rates following a 10% increase in q10 depends on the process-specific baseline q10 value (Table 1) and ambient temperature (Equation 2). Thus, the same perturbation can produce different process rate changes among basins due to temperature differences and among processes due to their different baseline q10 values."

Line 421 (denitrification/NH4)

Comment: Denitrification does not facilitate the production of NH4, it converts NO3 to N2.

Response:

The referee is right, oxidation of NO3 yields N2. However, the mineralized organic matter in this process end up, inter alia, as NH4. We reformulated the sentence to be more clear.

Changes to manuscript

... facilitates the production of NH4 as a final product of the mineralization process.

Line 427

Comment: If you suggest that the oxygen-rich environment in the southern and northern Baltic Sea supports coupled nitrification and denitrification, please give evidence from the literature for that.

Response: Thank you for the comment. We have now included relevant literature to support this statement.

Changes to manuscript: The references added to the text are as follows

1. Tuominen, L., Heinänen, A., Kuparinen, J., & Nielsen, L. P. (1998). Spatial and temporal variability of denitrification in the sediments of the northern Baltic Proper. *Marine Ecology Progress Series*, *172*, 13-24.

2. Conley, D. J., Bjorck, S., Bonsdorff, E., Carstensen, J., Destouni, G., Gustafsson, B. G., ... & Zillén, L. (2009). Hypoxia-related processes in the Baltic Sea. *Environmental science & technology*, *43*(10), 3412-3420.

3. Stockenberg, A., & Johnstone, R. W. (1997). Benthic denitrification in the Gulf of Bothnia. *Estuarine, Coastal and Shelf Science*, *45*(6), 835-843.

Lines 433–434

Comment: Please give references.

Response: Thank you for the comments, We reviewed the literature and found contrasting evidence regarding the effect of regenerated production and small-phytoplankton dominance on carbon export (e.g., Richardson, 2019). We have therefore revised the text to avoid implying a direct reduction in carbon export and to acknowledge that the response depends on community composition and trophic interactions.

Changes to manuscript: The sentence revised from

"This shift can then impact the entire food web and may reduce the carbon export and potentially reduce the ocean carbon pump. However, in the Baltic Sea, such ecosystem shifts may be more constrained due to its unique ecological characteristics"

To

"Such a shift can alter plankton community composition and the pathways through which organic carbon is transferred and exported from the euphotic zone (Richardson, 2019; Bopp et al., 2005).. However, in the Baltic Sea, such ecosystem shifts may be more constrained due to its unique ecological characteristics (Reusch et al., 2018)."

The references added are

1. Richardson, T. L. (2019). Mechanisms and pathways of small-phytoplankton export from the surface ocean. *Annual review of marine science*, *11*(1), 57-74.

2. Bopp, L., Aumont, O., Cadule, P., Alvain, S., & Gehlen, M. (2005). Response of diatoms distribution to global warming and potential implications: A global model study. *Geophysical Research Letters*, *32*(19).

3. Reusch, T. B., Dierking, J., Andersson, H. C., Bonsdorff, E., Carstensen, J., Casini, M., ... & Zandersen, M. (2018). The Baltic Sea as a time machine for the future coastal ocean. *Science advances*, *4*(5), eaar8195.

Lines 476–478

Comment: This belongs into the results section.

Response: Thank you for the comment and the manuscript revised accordingly.

Changes to manuscript: The entire sentences removed from the discussion and pasted into the results under section 3.1.1 at line 284 after ".. compared to the Gotland basin"

Lines 480–482

Comment: This is the first mention of water column detritus in the discussion. Why is only water column detritus and not sediment detritus mentioned here? Perhaps it would be more interesting to discuss the different response of water column versus sediment detritus, perhaps it can be done in context with the Fe-P mechanism?

Response: Thank you for this suggestion. We have expanded the discussion to explicitly compare the effects of sediment and water-column detritus recycling. We clarify that enhanced sediment detritus recycling (E1_DetSed) modifies benthic remineralization and sediment–water nutrient exchange, whereas enhanced water-column detritus recycling (E2_DetWat) directly enhances pelagic regeneration produces NH4 and PO4 and subsequent nitrification. This distinction helps explain the contrasting NO_3 responses observed in the Gulf of Riga and Bothnian Bay in these two experiments. We further discuss the role of sediment redox conditions and Fe-bound P retention in the subsequent discussion of the contrasting PO_4 responses in the Bothnian Bay.

Changes to manuscript:

The sentence in line (480-482) has been revised to "Overall, our findings highlight the central role of detritus remineralization both in water column and sediment in driving the regional differences in nutrient dynamics. "

The following text added after line 457 where we were already discussing the constrasting responses in N in sediment and water column detritus experiments "The contrasting NO3 responses between E1_DetSed and E2_DetWat in the Gulf of Riga and Bothnian Bay indicate that the location of enhanced remineralization strongly influences the pathway through which regenerated nitrogen is processed. Enhanced sediment detritus recycling (E1_DetSed) increases benthic remineralization and modifies sediment–water nutrient exchange, where regenerated N H4 may be subjected to sedimentary nitrification and nitrate reduction processes. In contrast, enhanced water-column detritus recycling (E2_DetWat) directly increases pelagic regeneration of NH4, which can subsequently be converted to NO3 through nitrification under oxic conditions. Therefore, sediment and water-column remineralization represent distinct controls on nitrogen availability, and their relative importance depends on basin-specific environmental conditions, particularly oxygen availability and sediment–water interactions (Hietanen et al., 2012; Jäntti and Hietanen, 2012)"

The references added are as follows: Hietanen et al., 2012; Jäntti and Hietanen, 2012

Lines 506–528

Comment: This largely reiterates the method section.

Response: We agree that this part of the discussion largely repeated the definition and interpretation of the Scr metric already provided in the Methods section. We have therefore substantially shortened this paragraph and retained only a brief explanation needed to interpret the Scr results in the Discussion. The revised text now focuses on the scientific interpretation of the spatially heterogeneous Scr responses, which is discussed as follows,

Changes to manuscript:

The entire lines 506-528 removed from the manuscript and rewritten as follows

"To examine the role of coastal processes on the biogeochemistry of the deeper Baltic Basins, we defined a non-dimensional metric called relative coastal sensitivity Scr, which can quantitatively answer the question, which processes are the most relevant ones to investigate and confine, when we are interested in an accurate representation of the function of coastal zones for the basin-wide biogeochemistry. In this study, Scr values close to zero indicate that coastal perturbations have little influence on the deep-basin response, whereas values greater than one indicate a disproportionately large coastal influence relative to the spatial extent of the coastal zone. Negative Scr values indicate opposing responses between coastal-only and basin-wide perturbations. These contrasting responses highlight that the influence of coastal process parameterizations is spatially heterogeneous and depends on the process and basin considered."

Lines 552–567

Comment: Here you give an interesting explanation for the differences in the C and E experiments. Can you expand this section? Since most coastal waters are oxic, shouldn't this mechanism be visible in all investigated basins? Can you see in your model output that Fe-bound P really increases in the coastal zone?

Response: Thank you for this important comment. We have expanded the discussion to clarify why the contrasting PO_4 responses are particularly pronounced in the Bothnian Bay and why oxic conditions alone do not necessarily result in the same response across all coastal basins. The Bothnian Bay has distinct environmental characteristics, including permanently oxic sediments, low salinity and low sulfate availability, as well as relatively high Fe inputs, which favour strong phosphorus retention and burial. We also clarify that, although ERGOM represents Fe-bound P, it does not explicitly resolve the iron cycle. Instead, the effect of the unresolved Fe dynamics on phosphorus retention is represented through a latitude-dependent P-binding efficiency that is enhanced in the Bothnian Sea and Bothnian

Bay. Thus, the model parameterization accounts for the stronger phosphorus-retention capacity of these regions without explicitly resolving the underlying Fe cycling processes.

We further explain that the contrasting C1_DetSed and E1_DetSed responses can result from the interaction between this spatially varying phosphorus-retention capacity and inter-basin phosphorus transport. In the coastal-only experiment, enhanced sediment recycling in the Bothnian region occurs under relatively strong phosphorus-retention conditions, whereas in the basin-wide experiment, enhanced recycling also affects oxygen-depleted basins where phosphorus retention is weaker, allowing additional PO_4 to enter the water column and be transported northward. Thus, although oxic conditions favour phosphorus retention more generally, differences in sedimentary phosphorus-retention capacity and inter-basin transport can lead to different responses among different deeper basins analysed in our study. We therefore interpret Fe-associated P retention and inter-basin transport as plausible mechanisms supported by the model parameterization and previous observations and studies. A quantitative assessment of the Fe-bound P response and the underlying sedimentary processes would require analysis of additional model variables and is beyond the scope of the present study. This mechanism therefore remains a plausible hypothesis, supported by the existing literature.

Changes to manuscript: The following changes applied to the manuscript

1. We expanded the Discussion section to provide a more detailed explanation of the contrasting PO_4 responses between the C1_DetSed and E1_DetSed experiments.
2. We added discussion of why the proposed Fe-associated P retention mechanism may be particularly relevant to the Bothnian Bay and why oxic conditions alone do not necessarily result in the same response across all coastal regions.
3. We incorporated the role of spatially varying phosphorus-retention capacity and inter-basin phosphorus transport in explaining the contrasting responses.
4. We clarified that the mechanism explained through Figure 12 is proposed as a plausible hypothesis supported by previous observations and literature, rather than as a mechanism directly demonstrated by the present sensitivity experiments.
5. We also clarified in the Methods section, where the biogeochemical process rates are described, the latitudinal dependence of Fe-associated phosphorus binding in ERGOM and its role in representing spatial differences in phosphorus-retention capacity.

Could the Fe-P mechanism also explain why increasing sediment recycling has a different effect than increasing detritus recycling in the water column?

Response: Thank you for this suggestion. We considered whether the Fe-associated P retention mechanism could also explain the different responses to enhanced sediment and water-column detritus recycling. However, in our results, the contrasting response between E1_DetSed and E2_DetWat is most evident for nitrogen, particularly NO_3 in the Gulf of Riga and Bothnian Bay, whereas PO_4 does not show a comparable contrast between the two experiments. We therefore interpret the E1_DetSed–E2_DetWat difference primarily in terms of the different pathways of nitrogen processing associated with sedimentary versus water-column remineralization, as described in the Discussion (line 453-457 in the submitted manuscript).

For phosphorus, the location of remineralization may also influence the fate of regenerated PO_4 through sedimentary retention. In E1_DetSed, PO_4 regenerated during sediment remineralization is released in close proximity to the sediment and can therefore be retained through Fe-associated P binding before reaching the water column. In E2_DetWat, regenerated PO_4 is released directly into the water column and bypasses this immediate sedimentary retention pathway. Thus, Fe-associated P retention provides a potential mechanism for why sediment and water-column remineralization can affect nutrient availability differently, although the absence of a pronounced contrasting PO_4 response between E1_DetSed and E2_DetWat indicates that this mechanism is therefore not sufficient to explain a distinct basin-scale PO_4 contrast between these experiments.

Changes to manuscript: the following sentences added after line 457 as follows to describe the mechanism associated with contrasting NO3 response

"The contrasting NO3 responses between E1_DetSed and E2_DetWat in the Gulf of Riga and Bothnian Bay indicate that the location of enhanced remineralization strongly influences the pathway through which regenerated nitrogen is processed. Enhanced sediment detritus recycling (E1_DetSed) increases benthic remineralization and modifies sediment–water nutrient exchange, where regenerated NH4 may be subjected to sedimentary nitrification and nitrate reduction processes. In contrast, enhanced water-column detritus recycling (E2_DetWat) directly increases pelagic regeneration of NH4, which can subse quently be converted to NO3 through nitrification under oxic conditions. Therefore, sediment and water-column remineraliza tion represent distinct controls on nitrogen availability, and their relative importance depends on basin-specific environmental conditions, particularly oxygen availability and sediment–water interactions (Hietanen et al., 2012; Jäntti and Hietanen, 2012)."

Please also set your text in context to the findings of other authors about the phosphorus dynamics in Bothnian Sea and Bothnian Bay.

Response: We have therefore expanded this section of the Discussion to incorporate findings from previous observational and modelling studies on phosphorus retention under oxic conditions and phosphorus transport from the Baltic Proper towards the Bothnian Sea and Bothnian Bay. In particular, we now discuss the role of oxic sediments and Fe-associated P retention, the importance of the Bothnian region as a phosphorus-retention area, and the potential contribution of inter-basin phosphorus transport to the PO_4 response observed in our basin-wide experiment. We also clarify that the proposed Fe-associated P retention mechanism is a plausible interpretation supported by previous observations and modelling studies

Changes to manuscript: The discussion paragraph has been revised and expanded to include contrasting PO_4 responses in the Bothnian Bay in the context of previous studies. We added discussion of phosphorus retention under oxic sediment conditions, Fe-associated P retention, and previously reported phosphorus transport and retention between the Baltic Proper, Bothnian Sea, and Bothnian Bay.

The references added to the text are as follows

Caballero-Alfonso, A. M., Carstensen, J., and Conley, D. J.: Biogeochemical and environmental drivers of coastal hypoxia, Journal of Marine Systems, 141, 190–199, 2015

Savchuk, O. P.: Large-scale nutrient dynamics in the Baltic Sea, 1970–2016, Frontiers in Marine Science, 5, 95, 2018.

Savchuk, O. P.: Resolving the Baltic Sea into seven subbasins: N and P budgets for 1991–1999, Journal of Marine Systems, 56, 1–15, 2005.

Tamminen, T. and Andersen, T.: Seasonal phytoplankton nutrient limitation patterns as revealed by bioassays over Baltic Sea gradients of salinity and eutrophication, Marine Ecology Progress Series, 340, 121–138, 2007

Van Helmond, N. A., Robertson, E. K., Conley, D. J., Hermans, M., Humborg, C., Kubeneck, L. J., Lenstra, W. K., and Slomp, C. P.: Removal of phosphorus and nitrogen in sediments of the eutrophic Stockholm archipelago, Baltic Sea, Biogeosciences, 17, 2745–2766, 2020

Spilling, K., Olli, K., Lehtoranta, J., Kremp, A., Tedesco, L., Tamelander, T., Klais, R., Peltonen, H., and Tamminen, T.: Shifting diatom—dinoflagellate dominance during spring bloom in the Baltic Sea and its potential effects on biogeochemical cycling, Frontiers in Marine Science, 5, 327, 2018.

Conley, D. J., Bjorck, S., Bonsdorff, E., Carstensen, J., Destouni, G., Gustafsson, B. G., Hietanen, S., Kortekaas, M., Kuosa, H., Markus Meier, H., et al.: Hypoxia-related processes in the Baltic Sea, Environmental science & technology, 43, 3412–3420, 2009.

Conley, D. J., Humborg, C., Rahm, L., Savchuk, O. P., and Wulff, F.: Hypoxia in the Baltic Sea and basin-scale changes in phosphorus biogeochemistry, Environmental science & technology, 36, 5315–5320, 2002

Carstensen, J., Conley, D. J., Bonsdorff, E., Gustafsson, B. G., Hietanen, S., Janas, U., Jilbert, T., Maximov, A., Norkko, A., Norkko, J.,et al.: Hypoxia in the Baltic Sea: biogeochemical cycles, benthic fauna, and management, Ambio, 43, 26–36, 2014b.

Liu, Y., Meier, H. M., and Eilola, K.: Nutrient transports in the Baltic Sea–results from a 30-year physical–biogeochemical reanalysis, Biogeosciences, 14, 2113–2131, 2017.

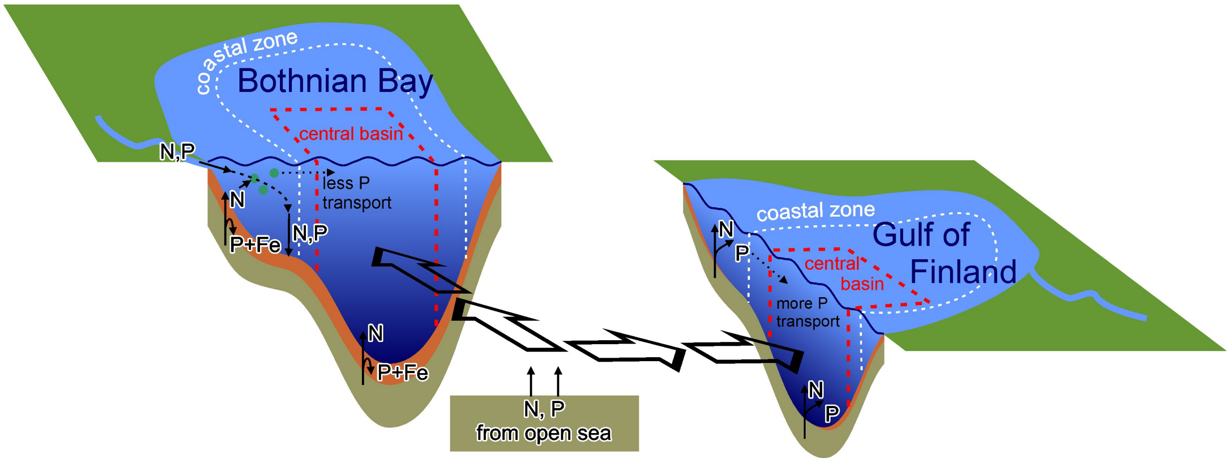
Figure 12

Comment: Figure 12 could be redrawn with more focus on the coastal zone. It should show the main components in your mechanisms e.g. Fe bound P. The Bothnian Bay itself has no adjacent anoxic basins, consider renaming the transport arrow. Perhaps it would even be beneficial to expand the figure and make a comparison to the Gulf of Finland or Gulf of Riga, where the coastal experiment increases PO4 in the water column? Can you give any evidence from your model – fluxes, transports – that local processes shape the response, or is there still an impact from changed N and P transport from the Baltic Proper?

Response: Three useful suggestions for Fig. 12: Focus on coastal zone, Inclusion of Fe as relevant player, Comparison to other basins without negative sign in relative coastal sensitivity. We also revised the transport pathway shown in the figure to clarify that PO_4 can be transported northward from the Baltic Proper through the Bothnian Sea towards the Bothnian Bay, rather than implying transport from an adjacent anoxic basin. The revised figure is intended as a conceptual representation of the proposed mechanisms.

The comparison with the Gulf of Finland provides additional context for the contrasting coastal responses observed in our simulations. In the coastal-only sediment-recycling experiment (C1_DetSed), PO_4 increases in the Gulf of Finland but decreases in the Bothnian Bay. This spatial contrast suggests that the response to enhanced coastal sediment recycling depends on basin-specific sedimentary P retention and nutrient transport processes. In the Bothnian Bay, strong P retention under oxic sediment conditions may limit the export of regenerated PO_4, whereas in the Gulf of Finland, weaker P retention and/or greater PO_4 release may allow more regenerated phosphorus to remain available in the water column and subsequently reach the deeper basin. We therefore consider the Gulf of Finland response to provide supporting evidence for our hypothesis that spatial differences in sedimentary P retention can contribute to the contrasting coastal responses. However, we do not directly quantify the individual PO_4 fluxes or transport pathways in the present analysis. Therefore, we cannot distinguish quantitatively between locally regenerated PO_4 exported from the coastal zone and changes associated with inter-basin transport from the Baltic Proper. We have clarified in the Discussion that the proposed Fe-associated P retention and transport mechanisms represent a plausible hypothesis supported by the model parameterization and previous observations, rather than mechanisms directly demonstrated by the present sensitivity experiments.

Changes to manuscript: We enhanced Fig. 12 according to your suggestion: (a) enlarging the coastal zone relative to the size of the basin, (b) adding "+Fe" to the sediment-trapped P, (c) including Gulf of Finland with less Fe-binding of phosphate, as a "reference basin" for comparison.



The discussion modified to include a comparison with the Gulf of Finland and Fe–P retention in comparison with the Bothnian Sea, supported by relevant literature, as follows:

Pitkänen, H., Lehtoranta, J., Räike, A., 2001. Internal nutrient fluxes counteract decreases in external load: the case of the estuarial eastern Gulf of Finland. Ambio 30, 195–201.

Lehtoranta, J., 2003. Dynamics of sediment phosphorus in the brackish Gulf of Finland. Monogr. Boreal Environ. Res. 24 58 pp

Conley, J., Stockenberg, A., Carman, R., Johnstone, R.W., Rahm, L., Wulff, F., 1997. Sediment fluxes along a eutrophication gradient in the Gulf of Finland, Baltic Sea. Estuar. Coast. Shelf Sci. 45, 591–598

Lehtoranta, J., Ekholm, P., & Pitkaenen, H. (2008). Eutrophication-driven sediment microbial processes can explain the regional variation in phosphorus concentrations between Baltic Sea sub-basins. *Journal of Marine Systems*, *74*(1-2), 495-504.

Lines 565–567

Comment: This does not seem to apply to all systems, but is mainly restricted to the Bothnian Bay. Can you identify under which conditions the coastal processes have this large and contrasting impact? What does this imply for efforts in model calibration?

Response: Thank you for pointing this out. We agree that the strong and contrasting coastal influence identified by Scr is not a general feature across all Baltic Sea basins. We have clarified that these responses are particularly evident in the Bothnian Bay, where several biogeochemical variables show high or negative Scr values. We further discuss that this behaviour may arise from the specific environmental conditions of the Bothnian Bay, including oxic sediment conditions and strong phosphorus-retention capacity, together with basin-scale nutrient transport. In contrast, the Gulf of Finland shows a positive Scr for PO4, indicating that the contrasting coastal-only and Baltic Sea-wide response observed in the Bothnian Bay is not universal.

For model calibration, these results suggest that coastal parameterizations should not automatically be prioritized across the entire Baltic Sea coastal regions. Instead, Scr can be used to identify specific basin–parameter combinations for which coastal parameterization may warrant particular attention. More generally, the Scr framework is not restricted to the Baltic Sea and could be applied to other marine systems where coastal and offshore environments differ in their biogeochemical process rates and spatial extent.

Changes to manuscript: The Discussion has been revised to clarify the conditions under which strong and contrasting coastal responses occur, including a comparison between the Bothnian Bay and Gulf of Finland. We also revised the discussion of the implications of Scr for model calibration and clarified its potential applicability beyond the Baltic Sea.

Summary and Conclusions

Comment: The summary and conclusion section should try to answer the four questions posed as the main aims of the paper (lines 118–124), i.e. 1) impact of q10 on Baltic biogeochemistry, 2) develop a methodology to assess coast-to-basin differences in response, 3) classify the response of the deep basins, 4) prioritise parameters for reducing model bias.

Response: Thank you for the comment. We have thoroughly revised the Summary and Conclusions to address the aims of the manuscript defined in the Introduction.

Changes to manuscript: The Summary and Conclusions section has been substantially revised,

Comment: In the revised manuscript, summary and conclusions should also reflect the revised discussion.

Response: Thank you for the suggestion

Changes to manuscript: The revised Summary and Conclusions now reflect the main findings and interpretations of the revised Discussion.

Lines 604–605

Comment: In the discussion you present PO4 trapping by Fe-oxides with baseline transport of P from adjacent basins as a potential mechanism for the response pattern in the coastal zone experiment in the Bothnian Bay. The conclusions focus on the response of the nitrogen species (and phytoplankton, but here Scr is negative for sediment recycling) – would addressing the nitrogen processes help in reducing model bias or should Scr values be interpreted differently?

Response: Thank you for this important comment. The high values of Scr for NO3 in the Bothnian Bay indicate that the basin response is particularly sensitive to perturbations of coastal process rates relative to coastal area. Therefore, these results identify the corresponding coastal parameterizations as potentially important targets for model evaluation and calibration, where improving their representation may help reduce model bias.

In contrast, the negative Scr for PO4 represents a different response, indicating that the coastal-only and Baltic Sea-wide perturbations produce responses of opposite sign. We therefore interpret Scr$ as a diagnostic metric that can identify parameterizations and regions requiring particular attention during model calibration, with the interpretation depending on the sign and magnitude of the metric.

Changes to manuscript: We have revised the Conclusions to clarify that high Scr values identify coastal parameterizations that may warrant particular attention during model calibration,

Lines 614–618

Comment: Would it be sufficient to focus on the model parameterizations in coastal areas that are sensitive to coastal q10 changes?

Response: Thank you for the comment!

We aim at a model tool suitable for the whole Baltic Sea ecosystem. Thus, parameterizations and process formulations should be valid for the entire model domain. For our purpose, it would be not sufficient to focus on a specific region. The Scr metric can nevertheless help identify processes and regions where coastal parameterizations may warrant particular attention.

Changes to manuscript: We have discussed this point in the revised discussion