Review for Biogeoscience entitled:

Biogeochemcial response of the Mediterranean Sea to Transient SRES-A2 climate change scenario by Richon et al.

This paper addresses the impact that climate change and future riverine nutrient inputs will have on the biogeochemistry of the Mediterranean Sea over the period 1980-2100 using a high resolution coupled NEMO/PISECES model. This paper is important for the scientific community as it is the first time a transient simulation on the response of the biogeochemistry of the Mediterranean Sea to climate change has been run. The authors separate the individual effects of the different scenarios to help determine the reasons for the future biogeochemical changes that the model predicts. In addition they looked at both the impact of each scenario to nutrients and the phytoplankton and zooplankton communities. This study concludes that nitrate concentrations in the Mediterranean are likely to increase in the future while there is no change in phosphate concentrations. They further predict a decrease in net primary productivity. In general, the use of English is good although there are some areas which need clarification which I have highlighted below. However I have some concerns regarding the initial conditions of the model and the analysis of model results which need addressing before this can be published. This review will start with more general comments before detailing more minor changes.

My main concern is regarding the initial nutrient conditions in the model. The authors state on line 212 that there is "some underestimation of nutrient concentrations" and again on lines 536-537 that "nutrient concentrations are slightly underestimated" but they do not quantify this. I was surprised when looking at Figure 4 to see deep water nitrate concentrations between 4 and 4.5 µM in the Western Mediterranean Sea. I was expecting to see nitrate concentrations on the order of 8-9µM and hence I do not call this a slight underestimation. Although there is a slight W-E gradient in nutrient concentrations within the model it is not anywhere near as strong as observations suggest. Together with the fact that nitrate in the DW is decreasing in the control scenario suggests to me that the model is not be capturing the biogeochemical cycling of nitrate correctly and raises the question of the validity of future model results. How does this underestimation of nitrate concentrations (and to a lesser extent phosphate concentrations) in the Western basin impact the results of changing circulation such as decreased deep water formation and increased stratification? Would this have a major difference on results? Can the model really predict future changes due to climate change if it can't predict present day conditions correctly?

My next concern is in regards to whether the authors include dissolved organic matter inputs though the Strait of Gibraltar and from rivers into the model? On line 291-293 the authors say that

"The Mediterranean is a remineralization basin that has net negative fluxes of inorganic nutrients (i.e. organic nutrients enter the basin through the Gibraltar Strait surface waters and inorganic nutrient leave the Mediterranean through the deep waters of the Gibraltar Strait"

However there is no mention of dissolved organic nutrients anywhere in this paper. Do the authors include them in the inputs through the Strait of Gibraltar (or in the riverine input)? If yes this needs to be explicitly stated and if no then they are missing a major source of phosphorus and nitrogen in their model (see Powley et al., 2017; 2018). In addition the paper tries to present a nutrient budget based solely on nitrate and phosphate and then use the imbalanced budget to explain the decrease in nitrate in the CTRL model (Line 540). However dissolved organic matter inputs need to be

included in the budget so that total N and P inputs and therefore a complete budget can be calculated (see Powley et al., 2017; 2018) In addition I suggest creating a Table summarizing the budget as currently it is difficult to interpret from the graphs. Finally Lazzari et al. (2014) conclude that dissolved organic matter is increasing in their model in response to climate change. Do your results agree? (I know this is not a key result but a sentence regarding this could be added to the discussion)

The results section is very qualitative with little quantitative analysis. Phrases such as slightly increase and significantly increase are common with no data to back them up. In addition I feel that section 3 and especially section 3.3 can be condensed as there is a lot of repetition and is hard to follow in places. This would make the main conclusions and outputs of the paper clearer to the reader. I suggest re-organizing section 3.3 to start with the nutrient budget first, analysing the different inputs and outputs from rivers, Straits of Gibraltar and sediment before going on to look at the effect of the different scenarios to nutrient concentrations. This way you can bring in the analyse from the budgets to explain the concentration trends rather than having to repeat yourself analysing and explaining the trends in nutrient concentrations before you have analysed the causes. I would also in general try and keep the same structure within each section in regards to the analysis i.e compare phosphate first, then nitrate, etc.

General minor comments

While I appreciate that you are limited by both data and computational power in your model runs I suggest refraining from using '*external inputs*' and instead be specific and use 'fluxes through the Straits of Gibraltar and riverine inputs'. As far as I understand you are not including atmospheric inputs, direct wastewater discharges or submarine groundwater discharges in your model which can all be considered external nutrient inputs.

Use Strait of Gibraltar or Gibraltar Strait throughout the paper rather than Gibraltar as Gibraltar is a body of land!

Detailed minor comments

Line 8: Change "coastal nutrients" to riverine nutrients. Coastal nutrient inputs could mean coastal runoff, direct wastewater discharges submarine groundwater discharge.

Line 9: Do you just mean from riverine inputs rather than external sources.

Line 27: I thought the last deposited Sapropel was 10,000 years ago not that they have been deposited for the last 10,000 years

Line 36: Please quantify the short residence time (i.e 100 year timescale) and add reference.

Line 40-41: Please re-phrase. The word transport in this sentence doesn't make sense.

Line 48: I am confused by the Adloff reference at the end. Do they also show this enhanced vertical stratification?

Line 49: remove "lead to"

Line 70: Add Heurtas et al. (2012) to the Gibraltar references. Add more references for atmospheric deposition or say 'and references therein'. There have been a lot of studies on atmospheric deposition in the Mediterranean region. What about direct wastewater discharges (Powley et al., 2016) and submarine groundwater discharges (Rodellas et al. 2015). Note also Powley et al., (2017;2018) have calculated a complete nutrient budget for the Mediterranean and these should be referenced somewhere in this paper.

Line 100: define the SST acronym rather than on line 222

Line 111: define the SSS rather than on line 222

Line 112: remove 'that'

Section 2.3 Please add a bit more detail regarding the biogeochemical model and the compartments so the reader has an idea of what is included without having to go to the references (i.e Are there compartments for bacteria, DOM etc?).

Section 2.3 Include a sentence regarding why you did not use atmospheric deposition, and other external inputs in this section.

Lines 150-155: Please be specific in which MEA scenario you use. None of the four scenarios are called business as usual. Also how did you combine values from the two Ludwig papers together as Ludwig et al. (2010) states that they are not directly compatible with one another.

Line 175: Why are 1966-1981 conditions used when the model results are from 1980 onwards? Please specify in the text.

Line 184: Write minus rather than using the minus sign as it wasn't clear to me what you meant initially.

Line 203 satellite not satellites

Line 212-213: Quantify the error. Compare model results with measurements. (See my main concern)

Line 224: When you say global I assume you mean across the entire Mediterranean. Please clarify

Line 229-235: I suggest moving this section to where you discuss the budget as no results are given and it confuses the reader

Line 230: Add references after "*nutrient budgets are highly dependent on external sources*".

Line 244-246: State this later on when you are talking about limiting nutrients.

Line 252: How much does the phosphate concentration decrease by? From what to what?

Line 253: Only use significantly if it is statistically significant. If yes then the state the statistics.

Line 254: Add "in the surface water in the Western Mediterranean Sea" after phosphate concentrations. The reader shouldn't have to look at the figures to know which water body you are talking about.

Line 254-255: What about the comparison between CTRL_RG and CTRL R?

Line 263: "*The eastern part of the basin contains approximately 50 % less phosphate than the western part.*" Where have you got this data from? Table 3 shows greater phosphate content in Western Mediterranean than Eastern Mediterranean. If you mean concentrations then I would still argue that your model is not showing 50% less.

Line 265-267: Give quantitative values.

Line 268: State which scenario you are talking about.

Line 272. Reference Figure 5 after Atlantic

Line 278-281: Consider consolidating with previous paragraph as there is a lot of repetition (especially concerning impact of rivers of nitrate concentrations).

Line 293: Reference needs brackets around it.

Line 295-298: Put quantitative results.

Line 305-307: What about statistics for nitrate?

Line 308: I suggest adding a figure showing the net fluxes through the Strait of Gibraltar to show imbalance. Again, I also suggest the authors look at total nitrogen fluxes to be able to determine whether there is an imbalance at the Strait of Gibraltar not just nitrate.

Line 315 Capitalise N in nitrate after full stop.

Lines 315-320: Is there a difference in the evolution of riverine discharge of nutrients between Western and Eastern basins? Combining everything into one flux makes this impossible to see, but if it differs it would have a large impact on results and may explain the differences to the riverine scenario seen in the two basins.

Line 328: Replace "This" with "The"

Line 329-330: put comma after occurs and flux

Lines 328-332: What happens to sedimentation in the CTRL-R and CTRLRG scenario? This will make the argument stronger whether sedimentation is linked to decrease in vertical fluxes. Also please be more explicit about the process that would increase phosphate and nitrate in the deep water. A lower particulate matter flux to the deep water would lead to lower remineralisation fluxes and therefore lower phosphate and nitrate. Alternatively, higher water temperatures could lead to higher remineralisation and therefore a lower sedimentation flux despite the same flux of particulate matter exiting the surface water. How do the authors know it is not higher temperatures rather than changes in the water flux that alters the sedimentation flux?

Line 334: A new section heading is needed before line 334.

Line 334: Into rather than in?

Line 334-335. Compared to when? The start of the model run? When you say the sum do you mean the balance between inputs through the Gibraltar Strait, riverine inputs and sedimentation? Be specific. Also, as mentioned before, I suggest including dissolved organic matter in your calculations and to produce a table to show the balance of the different inputs and outputs of phosphorus and nitrogen.

Line 350-351: The authors state *"changes in Gibraltar exchange fluxes of phosphate seem to have limited effect on Mediterranean phosphate content*" but on lines 305-306 they also state "*evolution of phosphate concentration in the Western basin is linked with Gibraltar inputs"*. Which one is it?

Line 353-356: What about increase in temperature effecting results? Luna et al., (2012) hypothesise increasing deep water temperatures will increase prokaryotic metabolism, thus potentially increasing nitrate and phosphate concentrations. Lazzari et al., (2014) also predict that increasing temperatures increase metabolic rates.

Line 378: Replace "and shows" with "showing"

Line 380: Delete as this is repeated and explained in the next paragraph.

Line 384" surface phosphate what? Concentrations? Masses?

Line 386-387: The decrease does not look that clear to me and it certainly doesn't become entirely depleted in phosphate.

Line 409: Remove would

Line 410-414: Why would the phosphate become the major limiting nutrient in areas where primary productivity is reduced?

429-430: Reduced by how much?

Line 433: Are we still talking about chlorophyll or primary productivity?

Line 434: What is "it"?

Line 441: Remove Adloff reference?

Line 452? Do you mean riverine nitrate inputs or total nitrate inputs?

Line 460-463: Which scenario are you talking about?

Line 463: Add Western Mediterranean Sea after diatom concentrations.

Line 465: Add diatoms after concentration

Line 478: Add references if other studies have concluded this.

Line 483: "After all" doesn't make sense in English. I suggest you use "Altogether".

Lines 494-497: Add references to this sentence

Line 514 and 515: When talking about “coastal nutrient inputs” and “coastal runoff” are you only talking about riverine inputs? Be specific.

Line 518: ‘developing’ not ‘developping’

Line 540: I don’t think you can say there’s an imbalance in sources and sinks without looking at the organic nitrogen aswell (unless you count nitrate sourced from DOM). There will always be an imbalance of nitrate in the Mediterranean if you only look at external sources as you mention yourself it is a remineralization basin.

Line 591-592: Please re-phrase the sentence and be specific to what you are talking about. What inputs?

Line 598: I disagree with this statement. There are lots of nutrients inputs that you haven’t considered such as direct wastewater discharges, diffuse runoff, submarine groundwater discharge.

Line620: Shown rather than showed

Table 2: It would be more informative to present the numbers per m^2 surface area and then comparisons between basins can happen as the Eastern Mediterranean is almost twice the size of the Western Mediterranean. The reader can still calculate the total mass if the surface area is given. Also taking the difference from the control rather than total values might make it easier to spot trends.

Figures 3 and 4: Please create a greater contrast between the CTRL R and CTRL RG. These are difficult to see at present.

Figure 5: it would be nice if the net flux of nitrate and phosphate across the Strait of Gibraltar could be added aswell.

Figures 8,9,10 and 12. I struggled to see the differences between the two time periods which were mentioned in the text. I suggest to produce a figure of the anomaly between 2080-2099 and 1980-1999 rather than having the 2080-2099 figure as it currently is. The changes with time will then be more evident to the reader.

Figure 10. Units in caption do not match units in figure

Figure 12: Why is the HIS/A2 scenario figures not presented aswell?

Figure 13: Units in caption are different than on figure

Figures 14 and15: What are the units? mmol m^{-3} of what? Carbon?

Figure A1: When were the data points collected? Would the HIS/A2 scenario be a better comparison than CTRL as it actually uses 1980-2000 data?

Figure A.2 Change P_4 to PO_4 in the label.

References

Huertas, I. E., A. F. Ríos, J. García-Lafuente, G. Navarro, A. Makaoui, A. Sánchez-Román, S. Rodriguez-Galvez, A. Orbi, J. Ruíz, and F. F. Pérez (2012), Atlantic forcing of the Mediterranean oligotrophy, *Global Biogeochem Cycles*, *26*(2), doi: 10.1029/2011gb004167

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Luna, G. M., S. Bianchelli, F. Decembrini, E. De Domenico, R. Danovaro, and A. Dell'Anno (2012), The dark portion of the Mediterranean Sea is a bioreactor of organic matter cycling, *Global Biogeochem Cycles*, *26*, doi: 10.1029/2011gb004168

Powley, H.R., Krom, M.D., Van Cappellen, P. (2018). Phosphorus and nitrogen trajectories in the Mediterranean Sea (1950-2030): Understanding basin-wide anthropogenic nutrient enrichment. *Progress in Oceanography,* 162, 257-270

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Rodellas, V., J. Garcia-Orellana, P. Masque, M. Feldman, and Y. Weinstein (2015), Submarine groundwater discharge as a major source of nutrients to the Mediterranean Sea, *Proc Natl Acad Sci U S A*, *112*(13), 3926-3930, doi: 10.1073/pnas.1419049112