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Title: "Pelagic primary production in the coastal Mediterranean Sea: variability, trends and contribution to basin scale budgets" by Paula Maria Salgado-Hernanz et al. 2021.

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Response to Interactive Discussion Referee #1. 1st revision (01-02-2021):

Dear reviewer, we would like to thank you the interest you have shown in our study and therefore consider it as suitable for publication in Biogeosciences. We then proceed to disaggregate and answer your comments:

Response to main comments Referee #1:

#1.1: One of the things that struck me was the higher primary productivity (per m^3) and chlorophyll data in the Eastern basin than Western basin which I found very surprising. Due to low river inputs in the Eastern Mediterranean compared to the Western Mediterranean I naturally would expect the Western Mediterranean coastal area to be more productive. I would like the authors to discuss this in more detail – is this due to the uncertainty/overestimation of chlorophyll in the Gulf of Gabes as mentioned by the authors or is there observational data to back up the high productivity here.

We agree. Averages are in this case misleading because distributions are not normal. In some shallow and highly productive regions this is particularly notable. In the case of PP (gC m^{-2}, see herein Fig. 1a) this compensated by the integration depth and, thus, the weight of these pixel, although relevant, is less critical than in PP (gC m^{-3}, see herein Fig. 1b) where the influence of vertically averaging just over few surface values exacerbates the differences with overall values. As shown in herein Fig. 1b, due to the lack of large shallow and productive areas, there are few values above 30 (gC m^3) in the western Mediterranean, whereas high PP is more frequent in the Adriatic Sea (red) and in the eastern Mediterranean (blue). If the pixels with values >30 gC m^3 are plotted (see next Fig. 2) it becomes evident that most of them are located in shallow waters of the Gulf of Gabes and in the Nile Delta, and less so, in the northern Adriatic. To avoid these problems, we refer now to median values in Table 2, yet mean values are still provided as a reference.

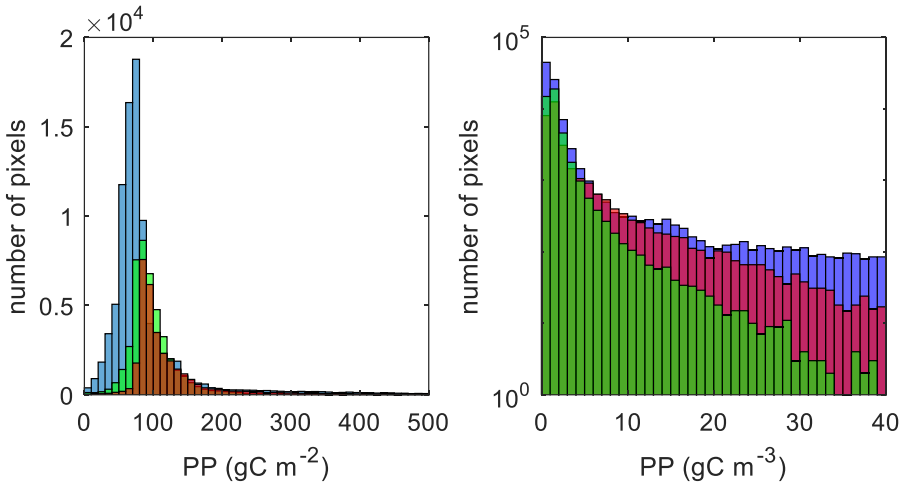

Figure 1. Frequency histograms for a) Integrated and b) vertically averaged PP estimations. Blue (East Med.) green (West Med), red (Adriatic). Note that Y-axis in Fig 1b is logarithmic.

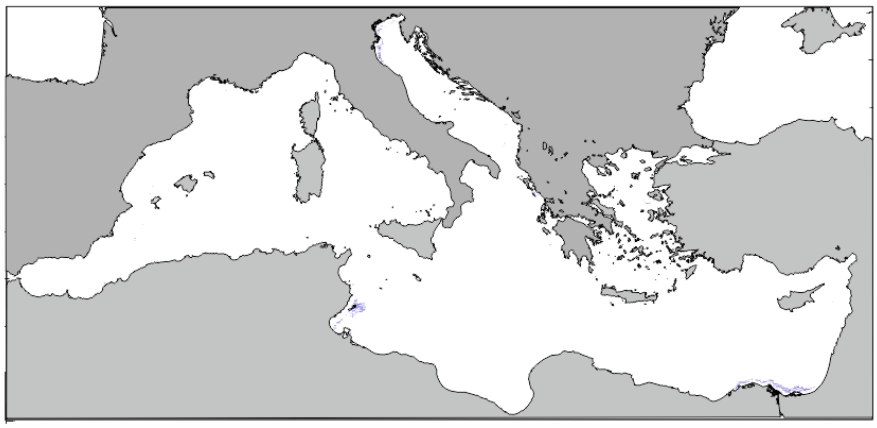

Figure 2. Map showing the location of the pixels with values >30 gC m^{-3} in blue.

#1.2: Can the authors put any error estimates on this or give a lower bound on the Eastern value.

We have maintained de standard deviation (S.D.) instead of the standard error (S.E.) because most published PP use this deviation descriptor in their studies.

#1.3: Likewise, can you really give a contribution of total primary production to the Mediterranean for coastal areas if the studies that estimated these total Mediterranean values exclude the highly productive coastal areas (i.e. North Adriatic, Gulf of Gabes) as mentioned by the authors on Line 76 due to the high turbidity and thus inaccurate values.

We use an improved Chl algorithm that is regionally tuned to consider the characteristics of the different Mediterranean regions. Certainly, this not exempt from inaccuracies due to turbidity, but it is much more accurate than previous algorithms used for PP estimations. See, also the following question #1.4:

#1.4: Alternatively is the CMEMS chlorophyll data corrected for these high turbidity areas, reducing the uncertainty in your estimates compared to previous studies like Bosc et al. 2004 and Bricaud et al., 2002 where these areas were excluded?

In the present study, we used the most adequate regional Chl product available up to date for the Mediterranean Sea. This ocean-colour data record is a regionally-tuned reprocessing of the climate-quality, error-characterized, and bias-corrected merged product of multi satellite observations (SeaWiFS, MODIS-Aqua and MERIS sensors) initially developed by the European Space Agency Ocean- Colour Climate Change Initiative Program (ESA OC-CCI) (Sathyendranath et al., 2017; Sathyendranath and Krasemann, 2014). Then, the Chl product available from CMEMS has been tailored to the Mediterranean region by using the regional algorithm MedOC4 (Mediterranean Ocean-Colour 4 bands, Volpe et al., 2007) for Case-1 waters and the AD4 algorithm (ADriatic 4 band, Berthon and Zibordi, 2004; D'Alimonte and Zibordi, 2003) for Case-2 waters. In this product, the merging of Case-1 and Case-2 information was performed following D'Alimonte et al. (2003). In practice, the CMEMS processor ingests the OC-CCI remote sensing reflectance, which is the result of a merging procedure that accounts for the inter-sensor bias among different sensors and then applies the specific regional algorithm. In the studies mentioned by the reviewer, no specific regional Chl algorithm was used. Both Bricaud et al. (2002) and Bosc et al. (2004) used Chl resulting from reprocessing #4, provided in July 2002 (see http://seawifs.gsfc.nasa.gov/SEAWIFS/RECAL/Repro4). The bio-optical algorithm was the ‘‘OC4v4’’algorithm proposed by O’Reilly et al. (1998).

#1.5: Following on from this I would like to ask the authors whether they have considered doing the analysis (with small adjustments) for the whole Mediterranean Sea so that comparison for coastal primary against the whole Mediterranean is coherent using data that has been prepared in the same way. This would enhance their conclusions on the contribution of the coastal zone to primary productivity in the Mediterranean.

The focus of the present study is the coastal zone of the Mediterranean Sea at a reasonable resolution to be able to identify the main coastal PP features and with the aim of defining different coastal regions that are oversaw in more general PP estimations. Therefore, we decided to exclude open ocean waters. We agree that running the entire Mediterranean Sea would be more coherent but, since there are plenty of studies providing this information (we do in fact review all of them in Table 2), we do not feel that this is a major drawback.

#1.6: Generally, the manuscript is well written and English is good. I do feel that the conclusions can be strengthened and it would be nice if the authors could specifically say how this dataset/analysis will be useful to the Mediterranean science community. If the authors address the comments I have made, I think this manuscript can be considered for publication in Biogeosciences. The attached supplement provides my detailed comments on the manuscript

We are thankful for the positive comment of the reviewer. We have now enriched the Conclusion section with several sentences explaining the importance of understanding coastal production and its long-term variability in the Mediterranean Sea. It now reads “*In summary, pelagic PP in coastal shelves of the Mediterranean Sea during the period 2002-2016 was estimated in this study for the first time using available satellite ocean colour product. We estimated that 12% of PP of the Mediterranean Sea is attributable to coastal pelagic production and from that, about 80% of*

this carbon fixation is sustained by regenerated pathways. High PP spatial variations were observed among the different regions, as mainly driven by major river effluents, exchanges with nearby seas (i.e. Black Sea and the Atlantic Ocean) and by local processes. Our study shows that some coastal areas are indeed highly productive (>400 g C m-2) and sustain a large percentage of overall coastal production. Indeed, their temporal variability could be of paramount importance to understand variations in higher trophic levels (e.g. Piroddi et al., 2017). Despite that temporal variability is dominated by interannual and sub-decadal variations, our analysis reveals a weak global negative PP trend in the Mediterranean Sea related to climate drive patters (i.e temperature increase).Our analysis also reveals a weak negative PP trend, which cannot be qualified as climate-driven because most of the temporal variability is dominated by interannual or sub-decadal variations and the satellite record is only 14-year long. Nevertheless, long-terms effects can be regionally variable (i.e. PP trends in the Adriatic Sea are positive) and variations inof decreases fluvial nutrient inputs, together with other processes such as ocean warming in coastal regions, including heat waves, deserve a closer look as longer ocean colour database becomes available. Finally, we identify 18 along-shelf zones based on their temporal PP patterns. Two main PP groups were observed: zones with strong cross-shore gradients, typically found in wider estuarine regions and homogeneous zones within narrow continental shelf areas. These two types of coastal waters clearly characterize the coastal area of a sea were coastal waters are otherwise strongly influenced by ocean conditions".

Response to attached detailed comments from Reviewer # 1:

#1.7: Title: I suggest removing pelagic as I currently feel the title is an oxymoron. I don't consider areas>5m deep to be pelagic?

We intended to clarify that we are not estimating the contribution of the benthic PP in the coast. We agree that, in some contexts, the term may be confusing in this context since pelagic often refers to open waters. Nevertheless, pelagic is also commonly used as opposed to benthic in coastal studies (ie, pelagic, bentho-pelagic and benthic fish classification). Some other authors (i.e. Macias et al., 2017) also use the term pelagic as opposed to benthic in coastal PP studies.

#1.8: Line 76: 'Coastal areas were generally ignored in such studies'. Following my statement above, both Bricaud et al. and Bosc et al. masked areas of high turbidity where data is uncertain. Please comment on what improvements have been made to the CMEMS data to make it relevant in this study (if improvements have indeed been made).

Answer to this comment has been provided in the response to main comment ***#1.4.***

#1.9: Line 152: How does this assumption impact your results? Are waters in the Mediterranean well mixed to 200m deep?

Given the variability in coastal waters, we consider that this is a better assumption that using global parameterization of the shape of the vertical profile as a function of the surface Chl obtained from deep open ocean waters. Assuming a homogeneous profile will bias the calculations in offshore boundary of the shelf, particularly during summer conditions when the contribution of the DCM is not accounted for. We state this now in the M&M section.

#1.10: Line 224: As already mentioned, considering that some of these authors exclude the productive areas that you are including is this a fair comparison? The analysis would be a lot stronger if the same dataset was used to compare coastal production vs total production in the Mediterranean.

Answer to this comment is addressed in comment ***#1.5.***

#1.11: Equation 1: Considering you assign a uniform chlorophyll concentration it is not really dependent on depth?

Yes, the chlorophyll concentration is uniform with depth. Irradiance, hence PP, are however varying with depth by virtue of how light propagates in the water column

#1.12: Line 236-238: The authors mention that the Eastern Mediterranean has twice the amount of coastal primary productivity than the western basin due to its size. However, primary productivity per unit volume is also twice the amount of western shelf and is also higher than that observed in the Adriatic? Why is this? This is not what I would expect, especially given the little river inputs along the coast of the Eastern Mediterranean.

As we explained in ***#1.1*** , mean primary production per unit volume exaggerates the production in shallow areas. We consider that mean values are highly affected by the production in these areas and, therefore, we refer to median values which reveal that coastal median PP per unit volume is 16% lower in the Eastern that in the western Mediterranean. Please, refer to Table 1 for the updated values.

#1.13: Line 241-242: What about the Nile delta and Gulf of Gabes – these stand out to me as high areas of primary production based on Figure 1.

The reviewer is right. It now reads '*However, in some coastal regions of the eastern basin like the Gulf of Gabes and the Nile Estuary primary production is outstandingly high (>300 g C* m^{-2}*)*'

#1.14: Table 1: What are the uncertainties? Standard deviation? Please state this in the caption

Yes, the uncertainties indicate the Standard Deviation (S.D). It is now specified in the caption.

#1.15: Table1: Why did you use a different product to estimate chlorophyll in the whole Mediterranean Sea or open ocean water rather than the same one as coastal waters? Why couldn't you also estimate primary productivity using the whole dataset? Then it is a coherent analysis and you are comparing like for like. It would then enable comparison of the coastal ocean vs the entire Med Sea in the temporal trend analysis too.

A detailed answer to this comment is addressed in comment ***#1.5.***

#1.16: Figure2/3. What is the difference between Fig 2c and Fig 3b?

Figure 2c shows the coefficient of variation (CV) of the mean primary production per unit area, in g C m^{-2}, of the surface waters. Figure 3b shows the CV of the mean productivity per unit volume, in g C m^{-3}.

#1.17: Figure 5/Line 303: The authors say there is no significant trend in primary productivity in the Adriatic based on Figure 4. Why then does the Adriatic actually show the largest trend in Figure 5 with almost the entire 'coastal' Adriatic showing a positive trend? Likewise, I can't really see any trends in the Western basin despite the authors saying there was a slight significant negative trend in the Western basin based on Figure4.

The reviewer is right and Figure 4 and Figure 5 could bring misunderstanding. Figure 4 showed a regional trend resulting from 15 points (one mean value per year). Moreover, from 2012 a reduction in PP is shown at every region with the exception of the Adriatic. The Adriatic region presented positive PP values for years 2013 and 2014 (see Supplementary figure 1) and this could change the PP trend when only 15 points are considered (i.e Figure 4). For that reason, now we only provide trends obtained calculated with the complete time series (as shown in fig 5).

#1.18: Figure 7: Are the alongshore (Z areas) also based on the temporal patterns as indicated by the main caption to the figure?

Yes, that is correct. SOM aggregates the characteristic temporal patterns according to their similarities. In section 2.3 Coastal regionalization we quote, line 18-190 "*Then, 18 alongshore marine ecoregions were obtained considering the most relevant cross-shore limits of the SOM-derived regions (Z1 to Z18).*"

#1.19: Line 358: The authors suggest enhanced production occurs in regions of freshwater influence. I would argue R7 is not. What other factors lead to high R7? Possibly domestic and industrial wastewater inputs?

We have rephrased this sentence. Now it reads, '*An exception is R7 pattern, which is exclusively located in the shallowest inner shelf of the Gulf of Gabes,..*' . In the discussion section, line 502, we suggest that the PP enrichment in that area may be associated with degradation of the water quality attributed to industrial and urban activities (Hamza-Chaffai et al., 1997; Zairi and Rouis, 1999).

#1.20: Line 369-372: Interestingly Macias et al. (2018) use model simulations to show that primary production in the coastal region of the Western basin (including Gulf of Lions) is mostly influenced by circulation patterns, not river inputs. I suggest the authors include this reference somewhere in this manuscript.

We now make reference to the paper of Macias et al (2017) L&O in the discussion section 4.1. '*Mediterranean coastal production is also supported by other sources such as local mesoscale processes (Macias et al., 2017).*'

#1.21: Line 400: But the eastern Mediterranean also had higher values m3 that the western basin so it is not purely due to the bigger surface are of the eastern basin?

The reviewer is right. It now reads *'Because of its extension, due to the increased productivity in regions like Gabes, the Nile and the northern Aegean Sea'.*

#1.22: Lines 400-410: What about the influence of wastewater inputs (Powley et al., 2016) and submarine groundwater discharge (Rodellas et al., 2015)? It is mentioned again later in the discussion but I think it should be introduced earlier.

These references have been added. We have also emphasized the importance of groundwater and nutrient-rich effluents from human activities in the 4th paragraph of the introduction.

#1.23: Line 431: What method did Barale et al., use? Is this also from satellites?

The sentence has been rephrase by "*Barale et al. (2008), using Chl anomalies derived from SeaWiFS data, observed a general decrease in Chl biomass in the Mediterranean Sea over the period 1998–2003*".

#1.24: Line 443-445: Are you referring to the Biomodal Osciallation System (BIOS; i.e., Civitarese et al. 2010) here? If yes, I suggest you refer to it explicitly.

We have added explicit reference to the BIOS. Now it reads' *Alternatively, the Bimodal Oscillating System i.e. the feedback mechanism between the Adriatic and Ionian (Civitarese et al., 2010) peaking between 2004 and 2006 could have affected mass and nutrient exchanges between the Adriatic and the north Ionian.*'

#1.25: Lines 475-485: What about domestic and industrial wastewater inputs into the sea? Powley et al. (2016) show they may be significant and certainly are likely to contribute to primary production in some areas of the Mediterranean coastline.

We have included an explicit reference to domestic wastewater (Powley et al. 2016) in this paragraph now.

#1.26: Table 4: Please state how the errors are calculated.

The caption now reads '*Mean and standard deviation (S.D.) are calculated from 14 year averages is calculated from 15-year averages (2002-2016)*'.

#1.27: Figure 8: The figure caption and figure do not seem to match to me. There appears to be nothing about seasonality in the figure

There was an error in the caption. The correct one is now included.

#1.28: Figure 9: What unit is annual PP in? Does it make a difference if you use m-2 vs m-3 vs total?

g C m^{-2}. It is indicated now in the figure caption.

#1.29: Line 546-547– “Our analysis also reveals a weak negative PP trend which cannot be classed as climate driven" – but on lines 456 you say “we observed an influence of climate scale variability on coastal productivity as suggested by the inverse correlations between ΣPP and SST and, more loosely, with NAO and MO?” I don’t agree/understand this conclusion based upon

Note: Line 546-547 refers to actual lines 579-580 in the conclusion section while line 456, it refers to actual line 491 in the discussion 4.2 section. We thank the referee for this inconsistency. It has been corrected.

#1.30: Conclusion: It would be nice if the authors could speculate how a dataset like this could be useful to the Mediterranean/scientific community. For example, could it be used to highlight coastal areas where additional monitoring should take place (Note the authors don’t have to use this particular example)

The detailed answer to this comment is also addressed in comment ***#1.6.*** We have extended the conclusion section.

Response to attached minor edits from Reviewer # 1:

#1.31: Line 84: rather than basin scale budgets I suggest the authors be specific and either say basin scale PP or basin scale carbon fixation.

We have changed it accordingly.

#1.32: Line 104: ‘whenever they exceeded about 3-times the mean’. Using “about” in this sentence makes it seem not very precise. Do you really mean to include this here?

We agree. The term “about” has been deleted. Thank you for the advice.

#1.33: Line 131: when you say day length do you mean hours of daylight?

It has been specified: “D is the day length or hours of daylight (h)”.

#1.34: Line 170 : For clarity I suggest adding coastline before Western, Eastern and Adriatic.

Done.

#1.35: Line 240 Gulf of Sirte – I suggest if places are mentioned, they are included in the map in figure 1.

The location of Gulf of Sirte has been added in Figure 1.

#1.36: Line 241: add north before western African.

Done.

#1.37: Table 2: Suggest using 'Mediterranean' rather than 'Global' .

Done.

#1.38: Line 316: Please rephrase as I don't understand what you are trying to say,

We agree. It has been rephrased to '*A significant negative correlation was observed between coastal ΣPP and SST (r=-0.63, p< 0.001; Fig. 6a) revealing a decrease in phytoplankton biomass as the sea warms up*'.

#1.39: Lines 318-323: Are these results shown anywhere: Perhaps they can be included in supplementary material?

They are not included in the manuscript. We run the analysis and in the manuscript we mention the results that were more relevant for the discussion.

#1.40: Line 550: MAW – This acronym is not defined in the text so please use full term.

Thank you. It has been added "Modified Atlantic Water (MAW)".

#1.41: Line 610 Bricaud reference – please provide full reference/link that works

Corrected.

#1.42: Figures: I suggest to avoid using the rainbow colour scheme as it can emphasize unrealistic patterns.

Thank you for the advice. The color has been changed.

References

Barale, V., Jaquet, J. M. and Ndiaye, M.: Algal blooming patterns and anomalies in the Mediterranean Sea as derived from the SeaWiFS data set (1998-2003), Remote Sens. Environ., 112(8), 3300–3313, doi:10.1016/j.rse.2007.10.014, 2008.

Macias, D., Garcia-Gorriz, E. and Stips, A.: Major fertilization sources and mechanisms for Mediterranean Sea coastal ecosystems, Limnol. Oceanogr., 63(2), 897–914, doi:10.1002/lno.10677, 2017.