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Discussions

Interactive comment on "Detection and attribution of global change effects on river nutrient dynamics in a large Mediterranean basin" *by* R. Aguilera et al.

Anonymous Referee #1

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The manuscript by Aguilera et al. deals with spatio-temporal patterns of nitrate and phosphate concentration in the Ebro river basin and tries to explain them by climate variability (seasonality, NAO) and anthropogenic impacts (land use, fertilizers, irrigation, river damming, waste water inputs). For that, they use 31yr time-series data (1980-2011) from 50 sampling location distributed over the Ebro river and its tributaries. For 37 sampling locations, they additionally analyze time series of stream flow. They use dynamic factor analyses to extract common temporal patterns of all the time series. The identified seasonal cycles, multi-annual cycles, and long-term trends. However, these patterns have a different weight at each sampling location and a substantial proportion of sampling locations shows opposite trends. Then, the authors use multi-

variate statistics to analyze the relation between the factor loadings associated to each pattern at each sampling location and the differences in catchment properties and other environmental drivers.

Overall, the manuscript is of potential interest for the readership of Biogeosciences. I would suggest the publication of the manuscript after some moderate revisions. In most of its parts, the manuscript is well written and the methods are clearly enough described. At some points, some clarifications are needed. In the following, I give some specific comments on methodology and results followed by more general comments on the text.

#1 In-stream/in-reservoir processes – catchment area

The authors analyze different potential drivers of the spatial-temporal patterns of fluvial nitrate and phosphate concentrations. Most of the identified drivers relate to the catchment properties and the sources of nitrate and phosphate. For the temporal patterns, in-stream and in-reservoir processes (in particular nutrient uptake by algae growth) play an important role as well. Consequently, the authors analyze reservoir capacity and location as potential environmental drivers. A potential driver of spatial differences in temporal patterns which could easily be addressed as well would be catchment area. This might not be a driver which changes over short time-spans, but, as a surrogate measure for average water traveling time, an important explanatory variable for the different identified patterns. The cluster analysis in section 4.3 and the related figures 3 and 4 suggest an upstream-downstream pattern and catchment area as explanatory variable seems thus promising. For instance, the pattern 3 identified for nitrates seem to become more important in upstream direction (clusters 4->1->2->3).

As I get it from the methods section (section 3.7), land use (i.e. different no-point sources of nutrients) is calculated once for the whole catchment and once for a buffer area around the sampling location. This provides the possibility to distinguish between non-point sources (i.e. agricultural areas) that are more upstream and those not far

from the sampling location. For the latter, in-stream transformation and retention processes play less a role than for the nutrient loads coming from farther upstream, due to the shorter traveling time. The catchment area could maybe add valuable information. With increasing catchment area, on the one hand, the average traveling time of the water coming from upstream increases, and, on the other hand, the relative contribution from the 10 km buffer area decreases.

In section 3.7, the authors write that they consider "reservoir capacity and location, waste water treatment plants (WWTP) discharge and location". From the manuscript, it does not get clear to me how they consider the location of reservoirs and WWTPs. This would be important to know, because the location (immediately upstream or farther upstream?) would likely have an effect.

#2 Instream/reservoir processes part 2 N vs P

The spatio-temporal patterns of nitrate and phosphate concentrations might influence each other. With regard to algae uptake of nitrate and phosphate, it would be interesting to know what is the limiting factor of algae growth in the basin. Is it either nitrate or phosphate, or another factor (like light limitation)? Nitrate and phosphate show different long-term trends, with phosphate decreasing in the 1990s and nitrate somewhat later (large rivers). Does this have an effect on in-stream/reservoir algae growth and nutrient uptake/retention?

#3 Land use change

The authors analyze time-series of nitrate and phosphate over the 31 yr period 1980 to 2011. They explain differences in increasing and decreasing trends by the areal proportion of different land use types. What time is represented by the used land use data? Was there a significant change in land use in the Ebro Basin over the last three decades?

#4 Climate change

The authors argue that climate change would have an effect on nutrient and phosphate concentration. They identify, however, only effects of climate on the seasonality and multi-annual cycles of phosphate and nitrate concentration which could be related to climatic seasons and the NAO. To show the effect of CLIMATE CHANGE on nitrate and phosphate concentration, they would need to identify a correlation between long-term trends in nutrient concentrations and climatic variables.

#5 Nutrient fluxes from land to sea

The lateral fluxes of nitrate and phosphate would be more interesting than the concentrations, because they directly describe the inputs of nutrients to the river or the exports of nutrients to the coast. The fluxes could be easily compared if they were reported relative to the catchment area (e.g. t N km-2yr-1 or moles m-2yr-1). It would be interesting for the readers what the spatio-temporal patterns of nutrient fluxes would be. Also for the long-term trend it would be more interesting to see if the flux of nutrients increased/decreased, in particular for the sampling location which is farthest downstream (because this sums up all the changes upstream and represents the final export to the coast).

#General Comments

Introduction

Page 5261

L 6: You should try to find a more suitable word for "action". Maybe "impact"?

L12-15: Please, shortly explain here why this would be a fundamental concern.

L22-24: I don't really understand this sentence. Are you talking about the eutrophication of the rivers themselves (then the concentrations of nitrate and phosphate in the water would be important) or about the eutrophication of the coastal waters (then the fluvial nitrate and phosphate fluxes would be important).

Page 5262

L1-3: Do you really mean "insight of the physical, biological, or socioeconomical events"? Or rather the impacts of these events?

L13-19: Maybe you should shortly explain and evaluate (strengths, shortcomings) of all of each methods.

L20: "Spectral analysis" was not mentioned before. What do you mean by "methods like spectral analyses"? Does this include all the methods named above?

L24-28: The meaning of this sentence is not clear to me. As I get it from the text, you need a good data coverage to identify local stressors and disentangle their effect from the effects of global stressors. Thus, you try to avoid discarding time-series from your data pool and rather opt for an advanced method which can get valuable information out of less-consistent time series. If that is the case, you should clarify this here and write it in a more comprehensible way.

3 Methods

Page 5264

L14-15: How do you defined patterns? Are these the temporal patterns, i.e. seasonality, long-term trends and multi-annual cycles? Please, clarify here.

L16: The abbreviation 'DFA' should be defined. It appears here for the first time.

Page 5266

L12-13: "significant trends that are not necessarily a straight line". Better use formulations like "non-linear trend".

Page 5268

L3-4: Do you have a reference for this?

L5-8: What is a "spatial error structure"? What are the other 5 options for error struc-

tures? Why is the Gaussian structure (=" Gaussian distribution" ?) the best option?

4 Results

Page 5270

L1-3: How significant is that trend, when 20 of the 50 stations show an opposite trend? Also in Fig. 1c, this trend is not visible.

In Table 2, the authors list the identified potential drivers of all identified patterns, also for pattern 3. For pattern three, they make the distinction between stations with a positive factor loading and stations with a negative factor loading. Interestingly, for both they identified 'Industrial area (%) UPSTREAM' as explanatory variable with the same positive coefficient. What does that mean? Please, discuss.

Page 5271

L3-17: Here, it would be interesting to see a similar pattern analysis for stream flow, because the authors identified a clear relation of nitrate pattern 1 to stream flow (Fig. 1e). Next, it would be interesting to see if stations with different factor for nitrate pattern 1 would also show different factor loadings for any identified pattern of stream flow.

Table 2: For nitrate pattern 1 – positive factor loadings, Mean air temperature (upstream) was identified as an important explanatory variable. This variable was also identified to show a strong negative correlation to nitrate pattern two (Fig. 1e). In Fig 1e,f, the nitrate patterns 1 and 2 do not seem that different, with a minimum in late summer, when average air temperature is highest. This is an issue that would have to be discussed.

Page 5272

L19-21: The authors showed that nitrate pattern 2 can be correlated to temperature and this might be due to biological activity, or phenology like the authors expressed it. While reading 'phenology', I think about terrestrial vegetation and, in this context here,

the control of terrestrial nutrient cycling on the exports of nutrients to streams. Here, the authors show that this pattern (pattern two) is most dominant in the far downstream part of the Ebro. If a terrestrial control was the cause of this temporal pattern, it would be interesting to know why this pattern is less dominant in more upstream parts. Might it be that this pattern is due to in-stream uptake of N and P by aquatic autotrophic production? Then, 'phenology' might be a bit misleading.

5 Discussion

Page 5273, L21-Page5274, L4: See comment before. The nitrate pattern 2 seems to be most dominant in the downstream part. Could this indicate that algae growth has a more dominant effect than phenology of terrestrial ecosystems? Or is this due to the fact that pattern 1 is lower (due to retention in reservoirs) and thus the relative contribution of pattern 2 is higher? But then, the pattern 2 driven by terrestrial ecosystem phenology would also be attenuated due to water retention in reservoirs and, thus, algae growth would be left as the driver for pattern 2 in the downstream section of the Ebro. Maybe you should discuss the potential downstream shift from terrestrial phenology to algae growth as biological control of pattern 2.

Page 5275: If the authors also showed their results from the DFA for stream flow, like they did for nitrate and phosphate in Fig 1, this could help interpreting and discussing the effects of NAO and ENSO on the patterns of nitrate and phosphate. So far, from figure 1, only the average 12 month cycle of stream flow is visible. In table 1, they also state stream flow oscillations at 1.5, 2.2, 3.2, and 4.2 yrs. It would be interesting to have these identified patterns for stream flow as a plot which could be directly compared to those for phosphate and nitrate. It would also be interesting to see if there is a long-term trend for stream flow, in particular at the site farthest downstream.

Section 5.2, first paragraph: Here, I got a bit confused and had to read through the text several times. From Page 5272, L27 to Page 5276, L4: Do you refer to the sampling locations with increasing trends? If yes, please clarify that in the text. You should try

C1804

to restructure the whole paragraph and make it more logical. For the explanation of decreasing vs. increasing rends, you should start with the terrestrial sources: what human activities might have decreased nitrate concentrations (e.g. more rational application of synthetic fertilizers, improved sewage water treatment) and what might have increased nitrate concentrations at other sampling locations. Then you should come to the differences related to upstream-downstream patterns. Of course, head water streams might show stronger increasing trends if the sources increased, and decreasing trends when the sources decreased. Smaller catchments are likely more homogenous than larger catchments, that means that it is more likely that either decreasing or increasing terrestrial inputs prevail. Larger catchments, in particular because the catchments here are nested and large catchment contain multiple small sub-catchments considered here, will more likely contain a mix of increasing and decreasing terrestrial sources. Further, due to longer traveling times of the water, and additionally the impact of reservoirs, increasing nitrate inputs might also cause increased algae uptake (and denitrification?) that might attenuate increasing trends at downstream locations.