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Interactive comment on "Spatio-temporal controls of C-N-P dynamics across headwater catchments of a temperate agricultural region from public data analysis" *by* Stella Guillemot et al.

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We thank Referee #2 for his/her positive evaluation of the study: "The multi-element, many sight approach utilized does provide interesting insight into the potential influences of changing seasonal hydrology/ flowpath and landscape characteristics on the biogeochemistry of the study region."

He/she raised two major comments:

1) "The paucity of other studies focusing on multi-element patterns, in headwater streams, that examine seasonal patterns, or that focus on multiple catchments is some-

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Discussion paper

what overemphasized in the framing of the research though and further cross comparison with studies that include all or only some of those criteria would benefit the introduction and discussion.”

And specific comment on Lines 65-75- "I understand the point that the authors are making here, but there are actually a number of studies meeting most of these criteria that could be helpful in interpretation of results and in understanding the generality of the patterns observed across regions. A couple of ideas that came to mind when reading this section were:

-Fasching et al. 2019 in Ecosystems also use GAM models and the approach used to explore multiple drivers may be helpful, Natural land cover in agricultural catchments alters flood effects on DOM composition and decreases nutrient levels in streams - https://doi.org/10.1007/s10021-019-00354-0

-Although larger watersheds in the region are also included in the analysis I would suggest that some comparison should be made with Moatar et al. 2017, WRR, Elemental properties, hydrology, and biology interact to shape concentration- discharge curves for carbon, nutrients, sediment, and major ions https://doi.org/10.1002/2016WR019635

-The review and conceptual paper presented by Kaushal et al. 2018 in Biogeochemistry may also be helpful in evaluating the role of season and land use on multi-element water chemistry."

Indeed, and in the Introduction paragraph L45-54, factors of spatial variability in concentrations are reviewed from various contexts (headwaters or not) and from studies that analyzed at least one of the three elements. Similarly, the following paragraph L. 55-65 reviews seasonal variations in at least of the three element concentrations but without filter on catchment size or number of catchments included in the analysis. Therefore, we highlighted the scarcity of studies dealing with multi-element and multiple catchments, in headwater streams and including analysis of seasonal pattern in the introduction section only to describe the need for more investigation, which our work aims to contribute to (Lines 66-74).

We thank referee # 2 for the relevant additional references, and according recommendations from referee # 1 too, we suggest the following modifications in order to position our study in regards to these published results in the introduction:

"Besides being spatially variable, C, N, and P concentrations also vary temporally. The variability of concentrations with flow has been described in several studies using concentration-flow relationships at event (Fasching et al., 2019) or inter-annual to long-term scales (Basu et al., 2010; 2011; Moatar et al., 2017). Concentrations also vary seasonally in streams and rivers ..."

"We hypothesized that: 1) Human (i.e. rural and urban) pressures determine spatial variability in NO3 and SRP concentrations (Preston et al., 2011; Melland et al., 2012; Dupas et al., 2015; Kaushal et al., 2018), while soil and climate characteristics determine that in DOC and possibly SRP (Lambert et al., 2011; Humbert et al., 2015; Gu et al., 2017)."

Please see also the reply to referee # 1, major comment 2.

2) "Regarding the GAM model used to describe seasonality, this is a useful approach, but I also wonder if there may be opportunity to modify the presentation and possibly the models slightly to explore interactions between multiple drivers (e.g. season x land use or flow x soil)."

We thanks referee #2 for the suggested reference of Fasching et al., 2019, which is indeed very relevant here. In the presented study, we used GAM to described the seasonal patterns from concentration measurements. We used then correlation analyses with Land uses, flow and soils to see if they had a relationship or not with those seasonal patterns. The approach suggested by referee # 2 to fit the GAM according to time but also land use, flow and soils could be another way to explore these relationships indeed but the possible interpretation of the GAM should not be different from the one we could have using the correlation analysis.

Note also that, we tested a GAM fitting using both the month and the year in order to extract a long-term component (lines 175-179). The model sometimes failed in converging, and then it seems reasonable to limit the GAM complexity and to keep a two-steps analysis: 1) extracting seasonality using GAM and 2) analyzing the relationships between the extracted seasonality and the geographical variables.

Reply to specific comments

Lines 45-50 – "There have been a number of studies in Canada and United States to evaluate the influence of agricultural land use on DOC concentration and DOM composition. Although the statement that composition is usually quite altered is true, often concentration is more a function of the same factors as in non-agricultural catchments, in particular the presence of wetlands and soil drainage properties."

Indeed, DOC concentration has been primarily linked to topography and presence of wetlands and saturated areas which is true both in forested and agricultural catchments. As also suggested by referee #1, we suggest adding more references (lines 45-47):

"DOC concentration in streams has been related to topography, wetland coverage, and soil properties such as clay content or pH (Andersson and Nyberg, 2008; Brooks et al., 1999; Creed et al., 2008; Hytteborn et al., 2015; Temnerud and Bishop, 2005; Zarnetske et al., 2018; Musolff et al., 2018)."

Line 68 - This is true, but there is a lot of study that goes on further upstream in even smaller catchments where land management can be linked directly to impact.

Indeed, we did not state that there were no literature at the scale of headwater catchments: several studies at such scales in agricultural or impacted contexts focused on the link between specific land management practices and water quality. However, such studies rarely compare more than 100 catchments like we did in the present study in order explore the spatial variability of this link between land management and impacts.

Line 73- maybe also ad “multi-element” to this statement because there are many studies that examine multi-catchment patterns for a single element.

We suggest to rephrase as “multiple-catchment studies” on multiple elements are uncommon”.

Line 109- This is good. Often selecting sites in a stream network without spatial independence is a pitfall for many site studies in a region, particularly when working with data where the authors did not chose the original sampling locations.

Yes, it was for us an important criterion to focus the analysis on the spatial variability and not on the “longitudinal” variability within nested catchments.

Line 111- Please explain why these criteria were used for outlier selection and how commonly extremely high concentrations were observed.

The concentration databases initially included some extremely high maximum NO3, PO4 and Ptot values. We could clearly interpret these as outliers. Our thresholds for the selection of outliers (values > 200 mg N.L-1 or 5 g P.L-1) were chosen: 1) by expert advice (producer of the data) and 2) after verification on the data (in terms of proportions of values eliminated on each time series and number of time series concerned). Among the 185 NO3 time series, 3 were concerned and for Phosphorus 5 were concerned. Only one value was removed by time series.

109-112 – Were data examined to ensure that there were not seasonal biases in the timing of missing data and that certain sites were not heavily sampled only in one season (summer samples only for example)

We have imposed a criterion for selecting the time series according to the sampling frequency (at least 6 years of data with at least 8 values per year). We also looked at the data to see which months were least sampled and in the OSUR database no bias was observed as it is based on fixed and regular frequencies while in the HYDRE /

BEA we noticed a few time series where summer periods were actually less sampled but for some years only(over the 10 years). We suggest adding this information in the main text.

Line 185- The seasonality metric is interesting, but doesn't really separate the flow condition or discharge from other factors like temperature that vary seasonally. Calculation of a similar metric for high flow vs low flow for comparison to the SI might be quite revealing. An example of that method is in Fasching et al. 2019.

Indeed, but in the studied catchments, high flows are well in phase for all the catchments with maximum of discharge in winter (colder season) and low flows are all occurring at the end of summer (warmer season). Therefore, the suggested metric is relevant but it would lead to the same results as our seasonal index with this data set of catchments. However, a seasonal index based on season only has the advantage of being applicable even if there is no stream flow data, and in such case, the interpretation of the index should be adapted of course.

Figure 4 – I think the information displayed here is valuable, but I wonder if a visual with additional information might be possible with the GAM results if the influence of 2 different drivers were displayed in a 3d version of the figure similar to Figure 7 in Fasching et al. 2019. It could be discharge or land use on the other axis.-

We think that the use of the GAM proposed by Fasching et al., 2019 is fully valuable and interesting. However, in the way we used the GAM here, we first smooth the observations to compute metrics on the average seasonal pattern of concentrations, and then, we investigated potential drivers within a correlation analysis between catchment descriptors and concentration metrics. Again, given the relative moderate number of concentration points in each station, fitting the GAM on both temporal (month) and spatial (geographic variables such as discharge or land uses) variables could be difficult (see also reply to major comment 2).

Discussion-The discussion on DOC/NO3 patterns is well written and I agree with the authors general interpretation of the results.

Thank you.

For the SRP discussion it may be worthwhile to reference the strong correlations that have been observed in small agricultural catchments between soil P and runoff concentrations. There are metrics included in the predictor dataset for TP_soil and P surplus which appear to be model outputs. It may help with interpretation of results if it can be noted whether these follow anticipated patterns of buildup where more intensive livestock or fertilizer input is occurring.

We suggest adding such discussion to subsection 4.3., line 376:

“Nonpoint sources of P in agricultural runoff, historical inputs of fertilizer and manure in excess of crop requirements have led to a build up of soil P levels, particularly in areas of intensive crop and livestock production (Sharpley et al., 1994). This led to correlations between soil P and runoff concentrations in agricultural catchments (Cooper et al., 2015; Sandström et al., 2020), as found here.”

Sharpley, A. N., et al. (1994). "Managing Agricultural Phosphorus for Protection of Surface Waters: Issues and Options." Journal of Environmental Quality 23(3): 437-451.

Sandström, S., et al. (2020). "Particulate phosphorus and suspended solids losses from small agricultural catchments: Links to stream and catchment characteristics." Science of The Total Environment 711: 134616.

Line 380 – In the context of the observed seasonal pattern can you comment on the timing of nutrient applications and whether there is potential for depletion of soluble sources over time or not.

As explained in reply to previous comment, the inputs of fertilizer and manure in excess of crop requirements have led to a buildâĂŘup of soil P legacy storage (Sharpley et al., 1994), which gradually leaches into the water for decades (Sandström et al., 2020).

Therefore, the timing of current nutrient applications is likely to be invisible in the stream concentrations due to such time lags. Therefore, the correlations found between SRP C50 and variables related to P sources (TP_soil, domestic point sources, P surplus. . .) are significant but weaker (Line 287).

Table 1 – Presumably some fields are used for both summer and winter crops. A total % cropland variable might be useful if not already considered

The "Winter crop" variable corresponds to crops with a winter plant cover and a phenological maximum in April, thus relating to three major crops: wheat, barley and rapeseed. The "Summer crop" variable corresponds to crops with bare winter soil and a phenological maximum in early summer (July), thus relating to two major crops: corn (and sunflower but it is not cultivated in the studied region). We distinguished these two types in order to refine the proxy of pressures regarding potential NO3 leaching (higher for summer crops because of potentially bare winter soils). Adding the total percentage of cropland would not add more information than the percentages of grassland and forest.

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