

Interactive  
Comment

## ***Interactive comment on “Warming increases carbon-nutrient fluxes from sediments in streams across land use” by S.-W. Duan and S. S. Kaushal***

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Received and published: 27 November 2012

### General Comments

This research addresses an interesting and relevant scientific question, within the scope of BG, using novel ideas and data. Specifically, the authors ask, how does land use and climate change affect sediment flux carbon and nutrient fluxes in stream sediments? However, this manuscript requires a large amount of editing and additional information. This paper could be much stronger if the procedures, results, and conclusions were presented more clearly. The methods need more detail. I had many both minor and major questions as to why certain procedures were followed and how decisions were made in the specific comments below.

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Specifically, in the statistics, you need to be much clearer about how you are grouping your data. It was difficult to interpret results due to this lack of clarity. Throughout the paper, a number of regressions are used, and the type of regression is chosen simply based on the best correlation co-efficient. The authors need to explain which potential regressions they compared as well as potential mechanisms that cause such different relationships. As it is, it feels that the statistics guides the ecology and that the regression-fitting is completely post-hoc without any hypotheses.

**Now we explain which regression we compared as well as potential mechanisms. We now do not group our data together. We made regressions of sediment biogeochemical fluxes with temperature site by site. If the p value is <0.05 for the regression, we assume there is a significant temperature effect. We have stated in the Methods section that 3 types of regressions were used - linear, exponential and logarithmic. This is based on different phases of bacteria growth curves, because many transformations of C, N, P and S are biologically mediated. Now, we show that DOC and SRP fluxes all increase exponentially with temperature, consistent with exponential phase of bacterial growth during short incubation time. Nitrate and sulfate may increase logarithmically, or initially increase and then decrease with temperature increase, representing another phase of bacterial growth curve. These patterns may indicate the microbial effects of denitrification and sulfate reduction. Exponential and logarithmic regressions were used when describing flux rate in response to temperature. Both exponential and logarithmic functions are well known phases of bacterial growth curve. Temperature can stimulate bacterial growth rate and functions as a mechanism. Linear regression was only used to describe change in ratios for DOM composition and changes in response to watershed characteristics such as percentage impervious surface cover.**

In the results section overall, your headings tend imply that you are first considering just temperature effects and then land use effects. However, there is a good deal of

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mixing in each section. You should re-name the subsections to better focus what is reported in each one.

**We have now re-named the subsections to represent temperature and land use.**

You also need to do a better job at separating concentrations from fluxes. Switching between these two abruptly was confusing and made some of your results unclear.

**We have now added transition sentences when we switch from concentrations to fluxes.**

The first three paragraphs of the Discussion section should be introduction – or at least parts of it, explaining why this is an interesting question and the pathways through which warming can affect fluxes. As it is, you should start the discussion section with a restatement of your results and then explain them, rather than describing examples from the literature. This could also be accomplished by restructuring the discussion section.

**We have now moved part of the first 3 paragraph of the Discussion to the Introduction. The Introduction and Discussion sections have been restructured to explain why this is an interesting question and the pathways through which warming can affect fluxes.**

Finally, a major finding of this paper is the estimate of how climate change and land use scenarios could affect carbon and nutrient fluxes. However, these estimations are not mentioned until the last paragraph of the manuscript. The methods and results of these findings need to be included earlier in the paper, before mentioning them in the conclusion.

**We have now moved the estimate to the end of the Results section.**

On a similar note, no conclusions are made about the interaction of land use and climate change. Based on the abstract, the title, and the comparison across land uses throughout the paper, it seems that a major finding should be the broad differences

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in response to climate change by streams of different land use. This is touched on multiple times, but seems to be overlooked as a major result. Addressing the issues described below with Figure 9 and discussing those findings more clearly in the text would help to address this problem. This research is exciting, but the authors need to improve their presentation to make the findings clearer and more convincing.

**We agree and have now added a section regarding the interaction of land use and climate change in the Conclusion section.**

Specific Comments

Title – should this be carbon and nutrient fluxes, rather than carbon-nutrient fluxes?

**The title has been changed to “carbon and nutrient fluxes”.**

P11297: L15-17. At what interval was stream temperature recorded? It was unclear if the monthly samples also referred to temperature. Regardless, this should also be included in Figure 2's caption. Also, why was this site selected for temperature data, rather than other sites? Was temperature data available at other sites?

**The temperature was measured monthly and GFVN is the only site that has long-term temperature data. We have stated clearly in Figure 2's caption.**

P11297: L17-19. Explain what you mean by, “the long term trend is not clear”. Was there analysis done on this?

**We have added statistics to the Results section. We tested the significance of the temperature record (mean, maximum, minimum) with time. Results show the p values are all >0.05.**

P11297: L21. Was this at baseflow? How long had it been since a storm?

**Yes. The samples were collected at baseflow. It was two days after a small size storm, with a peak flow 2.3 times of the flow during the sampling date.**

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P11297: L22-25. How were the sites for sediment collection selected? Did “randomly” mean using a random number generator? Over what study reach length did you use it?A

?Twas this all over 100 meters of the primary sampling site, for example? Finally, how did you decide to collect from 5 versus 10 (or some number in between) sites?

**We have now added more detailed information on sample collections regarding the question above in the Methods section. This includes information on reach length and the number of sites.**

Also, were water samples taken upstream of sediment collection, and were they filtered, to control for suspended sediment?

**Water samples were taken at the same location but prior to sediment collection. They were not filtered, and effects of suspended sediment were checked by performing only whole-water incubations.**

P11298: L1-2. Why were these temperatures selected?

**The temperatures were selected to match the occurrence of stream water temperature (0-30°C) in the long-term record. We used the highest temperature 35°C considering there would be a 5°C warming in future.**

P11298: L4-6. Although this is a laboratory experiment, the differences between mixing water and sediment in a flask versus high flow events in a stream should be mentioned. Especially considering the large differences in storm flow between urban and forested streams.

**We agree there should be differences between mixing a flask versus high flow events in a stream, and storm flow intensity varies with land use. We have now mentioned this difference in the Methods and Discussions sections. Our experiments were designed to characterize transformation during baseflow.**

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P11298: L9-10. Why were the samples kept in the dark?

**The samples were kept in the dark to simplify the incubation experiments. It's known that heterotrophic bacteria in sediment play a major role in C, N, P and S transformations. More work has been conducted on algal uptake in stream channels and we wanted to focus on sediment transformation, particularly those relevant to hypohetic zone.**

P11298: L1-10. You state that the flasks were left stationary for sediment to settle, but you also state that the incubations were kept swirling: : You need to make this clearer and also describe why you did these things.

**Now, we have made the description simpler, by stating that the flasks were gently stirred during the incubations to simulate water movement in streams.**

P11300 - 11301: L29 – L1. The sentence including, “As it was used as a case study for prediction” should be in the discussion section and explained further.

**This sentence has now been moved to the discussion section.**

P11300: L14-16. Make clearer if you grouped all landuses together to test for temperature differences.

**Now, we do not group all land-use together. We perform linear or non-linear regressions of sediment biogeochemical fluxes with temperature site by site. If the p value is <0.05 for the regression, we assume there is a significant temperature effect.**

P11301: L1-10. This should be moved to the Sample Selection or its own sub-section in Methods, as it describes data collection and not analysis.

**These sentences have now been moved for the reasons mentioned.**

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P11301: L1-2. Again, what was the resolution of the temperature data? If it was measured once a month, how did you decide what days and what times to measure data at? How did you correct for potential diurnal differences as you traveled between sites?

**We agree and now used recent high-resolution data from the Baltimore Long-term Ecological Research site. The temperature was measured daily at all sites for one year, and we take a monthly average.**

P11301: L4. Was this the length of the channel upstream of the sample site to the headwaters? Make this clearer, and describe what stream data you used.

**Yes, we use the length of the channel is from the sample site to the headwaters. We use stream network data from the USDA Geospatial Data Gateway for this calculation.**

P11301: L5. Why didn't you include the buried streams? I think you don't need to mention this, as most people don't consider those pipes to be streams. If you do include it, give justification for your decision.

**We still mention buried streams. These pipes comprise a substantial portion of the drainage network in Baltimore watersheds and they do not contribute much to transformation of bioactive elements (Kaushal and Belt 2012).**

P11301: L7-10. The description of sediment loading calculations: "the values of width and fluxes of each section of the Gwynns Fall were the averages of the beginning and the ending stations, while the average width of tributary 10 channels was assumed to be 2 / 3 of the value measured each tributary site" is very unclear. This needs to be re-written to be more understandable.

**We have now rewritten this sentence as "We calculated the width measured from cross-sections of the main-stem and tributaries. The values for measured sections of the main-stem (between two sites) were the averages of the beginning**

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and the ending stations. The cross section of the tributaries was measured at the downstream location, but not measured at the upstream location. The upstream location of the tributary reach was assumed to be ~2/3 of the downstream location.”

P11302: L1-5. If discussed, the humic-like fluorescence and protein-like fluorescence data should be shown in the supplementary materials at least.

**We have now added protein-like fluorescence data to the supplementary materials.**

P11302: L6-9. Again, the sentence, “Changes in DOC concentration, humic-like fluorescence,

protein-like fluorescence and P / H ratio during the 35 °C incubation were 0.2–2.4, 1.0–3.0, 0.5–1.3 and 0.2–0.4 times that of their original values, respectively.” Was very difficult to follow. Is this across all sites? Also, because this is all shown in Figure 3, this should be a description not a re-stating of data shown more clearly elsewhere.

**This comparison seems not necessary and we have now removed this confusing sentence. The same was done for SRP, nitrate and sulfate.**

P11303: L11-15. “the difference was significant if only rural and suburban sites (POBR, MCDN, GFGL and GFGB) were included together, where a positive temperature effect could be observed ( $p < 0.05$ ; Fig. 7).” I asked this earlier, but did you group all landuses together to test for significant differences between temperature groups? Or did you group all times within a given temperature incubation together? This needs to be much clearer. Perhaps more importantly, why did you group your data this way? The comparison of 4 urban sites to 1 forested, 1 ag, and 2 suburban sites that have been grouped together doesn’t seem realistic to me. I think the regression relationships much more convincingly describe the relationships observed than an artificial grouping of urban /non-urban.

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**We have now revised our statistics and do not group the sites. We performed regressions of sediment biogeochemical fluxes with temperature site by site. If the p value is <0.05 for the regression, we assume there is a significant temperature effect.**

P11303: L23-25. What about at 15, 25 degrees C?

**We have now added the correlation at 15, 25 degrees C.**

P11303: L25-27. Across all temperatures? If so, state this.

**Yes. This is for all temperatures, and we have now stated clearly.**

P11304: L1-8. You need to set up this end section better. Previously, this research focused entirely on how climate change and landuse could influence sediment fluxes. Here, you bring in additional variables that had not been previously discussed as potentially explanatory. You describe this mechanism later, but some foreshadowing here is needed.

**We have now rewritten this paragraph. We have stated clearly that stream water quality and sediment quality are correlated with ISC, and these intermediate indexes indicate possible mechanisms of how urbanization affects sediment biogeochemical fluxes.**

P11306: L7-10. In the sentence, “We speculate that an initial decrease in nitrate followed by an increase in later stages of the incubations was likely attributed to denitrification and/or immobilization occurring at lower temperatures and nitrification at warmer temperatures well over 10°C (FdZ-Polanco et al., 1994)”, does this imply that it takes that much time for the samples to reach the temperature of the incubation? This seems unlikely. Is there data to back this up? If I’m misunderstanding, then it would be good to make the mechanism you’re suggesting clearer.

**The reason for this change in nitrate during the incubation is not clear, and we have removed this sentence from the Discussions.**

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P11308: L11-17. You should also mention in the negating effect of much higher stresses on bacteria and fungi in urban streams, for example pollutants, and how that fits into your findings.

**We have added negating effects, stating much higher stresses on bacteria and fungi in urban streams.**

P11308: L21. Was % ash weight correlated with % ISC? This relationship needs to be stated, to understand how this is an intermediate variable between landuse and different nutrient fluxes.

**We have stated clearly that % ash weight is correlated with ISC, and this intermediate index indicates how urbanization affects sediment biogeochemical fluxes.**

P11309: L3-4. Same comment as above, but for sediment size, porosity, and composition

– are these related to land use?

**We have now made the same statement as for % ash weight.**

P11310: L20-23. This is the first time this table and prediction is mentioned. This is a really interesting finding and is even stated in the abstract. You need to include the methods used to make these predictions and the results in the appropriate sections, rather than describing them in the final conclusion of the paper.

**We agree, and have moved this prediction to the Discussion section.**

P11311: L23-24. You state that, “variability in extremes in water temperature are also important in urban streams”, but you need to explain how, if it relates to your findings, and if this variability in extremes was observed in the Gwynns Falls.

**Prior study (Kaushal et al. 2010) showed that the variability in extremes was observed in the Gwynns Falls. We have now added reasons why variability in extremes in water temperature is also important, and how it is related to this**

study.

P11318: Table 1. It would be helpful to state here if both landcover and impervious statistics were based 30-m resolution land cover data. Also, explain why the % of different land uses do not add up to 100% across the board. Finally, what does the row for runoff (m) refer to? This needs to be explained more clearly and referred to in the text.

**We have added in the notes of the table that both landcover and impervious statistics were based 30-m resolution land cover data. We have now added all land-use/cover and now % of different land uses do not add up to 100%. Runoff (m) data are not used in the paper and we have deleted them.**

P11322: Figure 1. In the map of the Chesapeake Bay area, there should be some labels to show the location – states, ocean, Baltimore City. Also, there appears to be writing near the highlighted Gwynns Falls watershed, but it's illegible. The location of the Pond Branch site is confusing – is it highlighted on the map of the Chesapeake Bay area? Is it actually located in relation the Gwynns Falls watershed as shown? This needs to be clearer. Finally, what resolution is this landcover data and what is its source? Also, what is the source of the stream channel locations?

**We have now added required information for map of the Chesapeake Bay area. The Pond Branch site is now highlighted on the map of the Chesapeake Bay area. We have now included in captions that Pond Branch site is actually located in relation the Gwynns Falls watershed as shown. The resolution and source of landcover and stream channel data are also added in captions.**

P11329: Figure 8. Are these linear regressions for all relationships? This should be stated. Also, why are these linear after so many other relationships used polynomial and exponential regressions? For the SO<sub>4</sub> at 35 degrees C incubation, the linear regression seems to be strongly controlled by the two heavily urbanized / high % ash weight sites, while there's a large amount of clumping at lower ISC / % ash weight.

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This relationship should be examined further and described more clearly.

**We've stated clearly these are linear regressions for all relationships. They are related to watershed characters in a linear manner. We chose exponential and logarithmic regressions for sediment biological fluxes with temperature due to known phase of bacterial growth curves.**

**We have now pointed out that “For the SO<sub>4</sub> at 35 degrees C incubation, the linear regression seems to be strongly controlled by the two heavily urbanized / high % ash weight sites”.**

P11330: Figure 9. Include a key for release versus retention. Urban (%) should likely be %ISC, as that's the urban indicator you've used here. The “electron acceptors” at the bottom of the graphics seem to add confusion, rather than additional information. Similarly, the many descriptions of “mineralization”, “nitrification >denitrification” are too much. I don't think those pathways are necessary in this graphic; they could be described in the caption or the text. Also, does this need to be 3-d? Couldn't it be 2-d, but with an additional y-axis to describe the flux? On a different note, if this is also meant to show the effects of high temperature at low urban development (which it probably should), perhaps this should be a surface or lattice? As it is, this figure doesn't represent well your concept.

**We have now mentioned in captions that positive and negative values are for release versus retention. “urban%” has been replaced by “ISC”.**

**All the unnecessary words have now been deleted.**

**We still keep the electron acceptors at the bottom of the graphics, but add a sentence in captions stating “The area at bottom of each box shows that oxygen, nitrate, Fe<sub>2</sub>O<sub>3</sub>/MnO<sub>2</sub> and sulfate sequentially acts as the primary electron acceptor as sedimentary organic matter (OM) decomposition intensifies”.**

**We still keep box graph. Although surface or lattice graph might provide addi-**

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**tional information, this box graph was chosen for clarity.**

Technical Corrections

P11295-11296: L25-60; L 1-3. The phrase “the interactive effects of land use and potential climate change” repeats here, in back to back sentences.

**We have now removed the repeated phrase.**

P11297: L3-5. The description: “The Gwynns Falls sites from Glyndon (GFGL), Gwynnbrook (GFGB), Villa Nova (GFVN) to Carroll Park (GFCP) traverse a rural/suburban to urban gradient (Fig. 1 and Table 1)” was a bit awkward and could be clearer. Changing the order of the phrases would fix this: “The Gwynns Falls sites traverse a rural/suburban to urban gradient from Glyndon (GFGL), Gwynnbrook (GFGB), Villa Nova (GFVN) to Carroll Park (GFCP) (Fig. 1 and Table 1)”.

**We have now made the changes as suggested.**

P11297: L6. Site MCDN’s full name is not written out prior to abbreviation.

**The full name of MCDN has now been added.**

P11297: L8. Refer to Villa Nova and Carroll Park by abbreviations.

**We have now replaced Villa Nova and Carroll Park by abbreviations.**

P11297: L15-17. It’s unnecessary to state, “that were described above and in Table 1.”

**We have deleted the unnecessary words.**

P11298: L3-4. Was the stream water used from the same site as the sediment? I assume so, but it should be stated explicitly.

**We have now stated explicitly that water and sediment were collected at the same site.**

P11298: L23-24. Is there a word missing at the end of the phrase, “with maximum of

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5”?

**We have now added “times” to complete the sentence.**

P11300: L16. Use a colon rather than a dash here, to avoid any confusion that 4 degrees C was actually negative 4 degrees C.

**This sentence has now been deleted.**

P11300: L20. The word “with” is probably a typo.

**This typo has now been removed.**

P11300: L26. This should probably read, “: : :there is a clear warming response: : :”

**We have now made such a change.**

P11301: L2. Don’t state both “at all sites” and “at the 8 sites”.

**This sentence has now been deleted.**

P11301: L11. This should be “Results”

**We have changed “Result” to “Results”.**

P11301: L13-14. Be sure to consistently use “land use” or “land-use”, here and elsewhere. Also, you don’t need to see the stream water “used for incubations”; just saying stream water is clearer and less confusing.

**We have now made changes and kept consistent.**

P11301: L22-25. The sentence, “The % ash weight and  $\delta^{15}\text{N}$  increased from 1.3 ‰ and 0.63 at the forest site (POBR) to 3.8–6.7 ‰ and 1.95–1.89 at the degraded urban sites DRKR and GFGR, respectively” was very difficult to follow, especially keeping track of which numbers referred to which site and which variable. This should be written more clearly. You could perhaps remove the % ash weight from this statement, as you describe it again in the next sentence.

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**We have now changed this sentence to two sentences in order to make clearer.**

P11301: L25-26. “The \_13C, on the other hand, displayed the opposite pattern, and a depleted value was observed at urban GFGR.” Again, this is a bit unclear – is this a significant relationship? And if so, what are the R2 and p-value? Or is this comparing sites overall?

**We have now rewritten this sentence in order to make clearer.**

P11303: L10. Re-phrase “highest value”. Perhaps greatest increase or release?

**We have now changed “highest value” to “greatest release”.**

P11303: L13. “positive” and “temperature” are misspelled.

**This sentence has now been deleted.**

P11303: L21. You have abbreviated ISC multiple times. Do it once, and then use ISC, or don’t abbreviate it.

**We have now deleted the unnecessary full name.**

P11305: L4. “Service” should be “serve”

**“Service” has now been changed to “serve”.**

P11306: L1. “release” should be “released”

**“release” has been changed to “released”.**

P11306: L20-23. The sentence, “Because phosphate cannot act as an electron receptor (as nitrate and sulphate), there is no a decreased sink for released SRP under anoxic conditions.” Has a number of typos and is unclear.

**The typos have now been fixed and the sentence has been rewritten.**

P11309: L11. This should be, “we did not account for all of these variables”

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**We has changed the sentence as suggested.**

P11311: L4-5. The statement, our results regarding warming effects on N fluxes show a larger variability than SRP if all land use type are included” needs to be re-worded to make sense – should this be “show a larger variability in SRP”?

**We have now re-worded.**

P11318: Table 1. ISC is the abbreviation for “impervious surface cover”, not “imperious land cover”. It would be helpful to state here if both landcover and impervious statistics were based 30-m resolution land cover data.

**We have now made the change as suggested.**

P11320: Table 3. Include the abbreviation of temperature to t in the caption. All figures. For all figures, do not repeat in the title of the figure something that is said elsewhere. For example, in Figure 2, you don’t need a title because the information is stated in the caption.

**The title in Fig.2 has now been removed. We have now included the abbreviation of temperature as t in the caption.**

P1139324: Figure 2. For the y-axis, add degrees or the symbol for degrees Celsius.

**We have now added the symbol for degrees Celsius.**

P11325: Figure 3. For the middle y-axis, list the unit as Raman Unit and don’t describe it in the caption. Also, label the sites by the entire row rather than in each plot?A? This was confusing. Do the same for Figure 5.

**We have now changed the figure 3 and 5 as suggested.**

P11328: Figure 7. Capitalize “rural”

**This figure has now been deleted.**

Supplementary materials. These should be combined to one graph, with the equations  
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in an additional table.

**This supplementary material has now been deleted.**

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## Review 2:

General Comments: Overall I think that the study is well thought out and executed.

The paper is well within the scope of BG and presents a novel perspective on the effects of warming on C,N, and P release from stream sediments. The paper is well structured but the style of writing was quite dense.

I am not convinced that the method used really reflects in-stream fluxes and there is a large potential for bottle effects due to disruption of sediment vertical structure and redox gradients, which may have influenced the results. Caution needs to be used when applying the data back to the real system (such as in table 4). However, I think that the temperature effect is real and this study makes a useful contribution to the literature.

**We have now added a paragraph at the end of Discussion section, discussing the difference between bottle experiment and the real system.**

Minor Comments

Page 2, line 6: Please clarify the statement. Lab incubations of what?

**The missing words have now been added.**

Page 4, Line 6: Why would we hypothesize that urban sediments should show a greater response to warming (Aside from that fact that this is what you found at the end of the study)? The hypothesis isn't really supported by the introduction. It might be more reasonable to predict a priori the opposite, that urban sediments are often contaminated by heavy metals and hydrocarbons that may inhibit microbial activity, therefore limiting the response to warming.

**We predict such hypothesis because increased water temperatures coupled with increased availability of carbon and nutrient sources can increase microbial activity in stream sediments, and accelerate transformations of bioreactive ele-**

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**ments. Microbial activity in urban sediments may be inhibited by heavy metals and hydrocarbons, but temperature may be the primary controlling factor in this study region.**

Page 7 line 24: Why the citation for Duan et al 2012?

**This citation has now been deleted.**

Page 8 Line 16: Remove “-“. It makes the 4 °C look negative.

**This sentence has now been removed.**

Page 11, Lines 1-3: split these up for clarity. “Forest sites exhibited a linear increase in nitrate: : ;, while agricultural sites exhibited a linear decrease in nitrate: : :”

**This sentence has now been rewritten as suggested.**

Page 12 6-7 Clarify this statement: “displayed an opposite (negative) correlation” to what?

**This sentence has now been removed.**

Page 14 Line 21: add a ‘t’ to not

**We have now made such change.**

Page 18 Line 21: You shouldn’t be introducing new data and analysis in the conclusion paragraph. Outline the methods that you used to generate table 4 in the methods section and present the data in the results section.

**We have now moved the new data in conclusion section to results section.**

Figures 5 and 6: I don’t think that the R<sup>2</sup> values are correct here. It appears that the regression is only being fit to the means. The error bars suggest that there is a lot of variance that is not being accounted for here.

**Now we have improved our statistics. We made regression of sediment fluxes**

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**with temperature site by site. If the p value is  $<0.05$  for the regression, we assume there is a significant temperature effect.**

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