Author’s response to Reviewers of Earth Surface Dynamics Manuscript egusphere-2023-2485:

Sourcing and Long-Range Transport of Particulate Organic Matter in River Bedload: Rio Bermejo, Argentina

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Legend
RC: Reviewer Comment; AR: Author Response; ☐: Modified manuscript content

Referee 1

General comments:

“Sourcing and Long-Range Transport of Particulate Organic Matter in River Bedload: Rio Bermejo, Argentina” by Dosch et al. have analysed a range of chemical signatures of organic material carried in the bedload of the Bermejo river which has no tributary inputs in its lowland reach. They have shown that bedload OM primarily reflects recently eroded OM, and that it’s rapidly transported to the mouth and likely comminuted during this transport. This is a thorough and well carried out study on a unique system, providing new and valuable insights into bedload OM dynamics. It is within the scope of ESurf, references relevant literature well, and describes the context, methods, results, and discussion clearly. The paper is also well written and presented, with some relatively minor technical suggestions for improvement below. The only substantial issue in terms of discussion/interpretation is the choice of the mixing model, as discussed below. I think overall this warrants minor revisions that can be assessed by the editors.

Specific comments:

RC 1: The efficient conversion of POMbed to suspended POM via comminution is one of the most interesting findings of this paper, in my opinion. Would there be value in discussing the potential implications of this more? For example, would it be possible to calculate a rough estimate of the rate of POMbed comminution into POMspm, from the “missing flux”? Acknowledging the difficulties in bedload sampling, of course. Yes, it is likely to vary with tectonics and climate, but probably not by a huge amount, and more likely to be strongly controlled by the type of POC (eg woody debris vs leaf litter) and river hydrodynamics, ie. turbulence + bedload grainsize (sand vs gravel) acting as the "comminuter"? Are there any experimental or field data showing similar comminution of POM? Could this be extrapolated to other river systems, acting as an “invisible” supply of addition POM to the suspended load? Overall, the transfer of POMbed into the total POM flux (dominantly SPM here, and likely in other river systems?), and the wider implications seem a bit lost in the long paper, and (to me, at least) seem worthy a bit more discussion/emphasis – but this is just a suggestion and the authors are free to disagree or to refrain from too much speculation.

AC 1: Thank you for these suggestions. We added some information on (the lack of) experimental and field data showing organic debris comminution (L653). We also added estimations of bedload loss into the suspended load, and the implications in other river systems and some tentative considerations on how this might be more relevant in other river systems (L752). We think an extended discussion might strain the scope of the manuscript, but agree that the observation of in-stream supply of suspended sediment from coarse debris deserves some attention.

To our knowledge, there are no experimental or field data showing similar comminution of particulate organic matter. However, Merten et al. (2013) suggested that physical breakage of large woody debris in streams is likely dominantly controlled by the structural properties and position in-stream of the organic matter, as opposed to hydraulic and geomorphic variables, concurring with our assumption. Further research is needed to determine the scope and controlling factors of physical decay of coarse organic matter in the water column.

The total suspended organic carbon flux is ~1.85×10^5 tC yr^{-1} at the Bermejo-San Francisco confluence (Repasch et al., 2021), suggesting that the estimated POM_{Bed} carbon flux near the confluence is less than 1% of the total carbon load. The Rio Bermejo exports ~2.24×10^5 tC yr^{-1} in suspension downstream to the Rio Paraguay, implying that about 0.39×10^5 tC yr^{-1} of suspended organic carbon are delivered to the lowland channel by lateral erosion (Repasch et al., 2021). If we take the downstream estimates of bedload C flux at face, and assume this loss transfers to the suspended load, a mass balance suggests that less than 1% of the suspended load gain between the confluence and LL_{-1} and LL_{-2} could be due to grain size reduction of the coarse organic load. While our bedload carbon flux estimates are tentative, it is clear that this eye-catching mode of organic carbon transfer is small in comparison with the fluvial export of organic carbon in the suspended load of the Rio Bermejo.

However, the Rio Bermejo's suspended sediment yield is exceptionally high (Sambrook Smith et al., 2016). Assuming the loss between the $HW_{South-1}$+ $HW_{North-1}$ and LL_{-1} and LL_{-2} transfers completely to the suspended load, 79% and 98% of POM_{Bed} would transfer into suspension, while simultaneously recruiting additional bedload. POM_{Bed} in rivers and sedimentary deposits could contribute substantially to the overall flux in river systems with lower suspended sediment yield, and where bedload dominates the fluvial sediment flux (Turowski et al., 2016), or in highly erosive headwater streams with short transport distances from recruitment to subsequent deposition and burial (Blair and Aller, 2012; Hilton et al., 2011).

RC 1: Is there any correlation of near-bed flow velocity and POMbed concentration? Seems like not – worth a mention that this is the case, either way. Also, it seems ADCP data was not available at all sites, so average velocity from other sites was used to then estimate the velocity in the ones with missing data – is this correct? This was not very clear, if so. Table 2 should include near-bed flow velocities where available, and the values used (and explanation of how they were estimated), where not available.

AC 1: The velocities for the sites without available measurements were not estimated, since we did not use velocity estimates for the flux estimates later in the manuscript. We still included the near-bed flow velocities in Table 2 (together with other suggestions regarding Table 2).

Overall, there is no correlation with the near-bed flow velocity and the transported bulk bedload, or the POM_{Bed} > 1 mm. This was not specifically mentioned in the manuscript.

The mass of organic bedload scaled loosely with the amount of clastic sediment collected (Fig. 4d), but there was no correlation with sampling material and near-bed velocities.

RC 1: I think a more consistent sampling site naming convention would benefit the reader. I felt in places it was difficult to follow and to remember all the different locale names and to cross-reference them constantly with river names, headwater vs downstream, etc etc. For example, HWnorth and HWsouth is intuitive and clear, so I would suggest using those more consistently throughout, instead of referring to "Pichanal" etc.

AC 1: Thank you for the suggestions! We adjusted the naming convention of the locations from the main sampling campaign in March 2020 and adjusted the naming throughout the manuscript.

In March 2020, we collected bedload material from cross-channel transects (Fig. 2a) at four locations upstream of the Bermejo-San Francisco confluence. At HW_{South}, we sampled the Rio San Francisco at Pichanal ($HW_{South-1}$, n=13) and at Caimancito ($HW_{South-2}$, n=2). At HW_{North}, we sampled the upper Rio Bermejo at Embarcacion ($HW_{North-1}$, n=10), and the Rio Colorado tributary ($HW_{North-2}$, n=4) (Fig. 1). Downstream of the confluence, we sampled the lowland Rio Bermejo mainstem at Puerto Lavalle (LL_{-1}, n=12), 481 linear km downstream of the confluence, and at El Colorado (LL_{-2}, n=8), 583 linear km downstream of the confluence (Table 1).

RC 1: In terms of interpretation / discussion, my biggest questions are related to the mixing model used: A bit more explanation of the modelling approach would be useful, even if it's replicating the Smith et al method, as it is not the most standard EMMA / monte carlo mixing approach, as far as I can tell. For example, were the endmember compositions resampled from a normal distribution, or a uniform one? How does the area optimisation work? What is the meaning of the final variance values? Etc.

Are you sure this method does not under-represent the potential mixing polygons? Given the large scatter in the samples comprising the different endmembers, and the quite large SD of the endmembers, the contours seem to plot very close together and to be very strongly constrained by the endmember mean/median value. I have not used this mixing modelling approach, but my guess is it has to do with the fact you are minimizing the convex hull area each time? What would the result be if you used a simpler monte-carlo resampling of the different endmembers from their distributions, without area optimization? If you think the Smith et al approach is better here, then I would suggest explaining how and why in a short paragraph

AC 1: Thank you for this suggestion. Regarding the mixing polygons, we revised the script and found an error in our code. This part of the code flips the grid data, and hence, the polygon was not calculated correctly. We corrected this, leading to a wider area of the $\delta^{13}C$ / $\delta^{2}H$ mixing polygon.

We think the Smith et al. model is appropriate here and is well suited to describe the potential mixing space of our data. Firstly, the model includes average and standard deviation of the sources, accounting for the variability in our data. The wide spread and overlay in our source data however, further suggests that significant end-member unmixing of the respective sources to the mixed POM_{Bed} signal is not expedient using the geochemical proxies applied in this study. Instead, we adapt the model to understand the large variability in the POM_{Bed} signal. Our aim was to determine the area of a possible mixing signal of the POM_{Bed} data, and in addition, evaluate the potential of missing POM_{Bed} sources. The model by Smith et al. (2013) utilizes not only the resampled source averages, but considers the distribution of the mix data (=POM_{Bed} data) within a pre-defined mixing space. The pre-defined mixing space and the subsequent point-in-polygon iteration is defined by the spread of POM_{Bed} data. Hence, the mixing space is optimized by considering the variability of the POM_{Bed} data. This allows us to deduce an informed source mixing space, while considering the POM_{Bed} distribution.

We added additional explanation to the mixing model. We rewrote Section 4.2.1 (now changed to 4.2.2) "Mixing model analysis" to that effect

> We defined three potential POM_{Bed} sources, from coarse organic debris we sampled at distinct elevations in the catchment: floodplain leaf litter (<320 m), headwater leaf litter (320-1000 m) and headwater POM_{float} (>320 m). Significant end-member unmixing of the respective sources to the mixed POM_{Bed} signal is not expedient using the geochemical proxies applied in this study. Instead, we aim to understand the potential mixing range of the widely spread POM_{Bed}. Our aim was to determine the area of a possible POM_{Bed} mixing signal of the sources within the geochemical parameters, and in addition, determine potential missing POM_{Bed} sources. We use a mixing-space model developed by (Smith et al., 2013a). In short, the model uses Monte Carlo simulations to iterate mixing spaces (="convex hulls") that demonstrate the probability that our observed POM_{Bed} samples can be explained by a mixing model of the proposed sources. The model utilizes resampled source averages and standard deviation, and considers the distribution of the mix data (=POM_{Bed} data) within a pre-defined mixing space.
>
> For our usage, we assume uniform source mixing of the POM_{Bed} samples, and no fractionation from the source composition of POM_{float}, floodplain, and headwater leaf litter δ^2H /ACL_{25-33} and δ^2H /$\delta^{13}C$ to POM_{Bed}. We use minimum and maximum boundary conditions based on our source data to define the extent of the initial mixing space: 25 to 35 for the ACL_{25-33}, -190 and -110‰ for δ^2H values, and -40 and -20‰ for $\delta^{13}C$ values. The initial mixing space is iteratively adapted over 2000 iterations, using source data average and standard deviation, resampled from a normal distribution. Through each iteration, a point-in-polygon algorithm tests if the mixed POM_{Bed} data remains within the mixing space opened by the source input. This ensures an "optimization" of the mixing space according to our POM_{Bed} data, assuming that POM_{Bed} sources are not fully represented by our included sources. The point-in-polygon algorithm is applied to a testing grid within the mixing space. With a grid resolution of 500, the point-in-polygon is tested on 500 × 500 values per iteration within the mixing region. Simultaneously, the area of the mixing area is assessed, and the variance between all previous iterations calculated. The stabilized variance value hence, represents the mixing space area the optimized mixing area considering the source distribution and the mixed POM_{Bed} data. The variance of the convex hull area stabilized after ~1000 iterations for the δ^2H /ACL_{25-33} model, at a variance of 40 ‰^{2}, and after ~1000 iterations for δ^2H /$\delta^{13}C$ at a variance of 60 ‰^{2}. The resulting mixing regions were not sensitive to variations of the boundary conditions. The results are plotted as derived mixing regions, with different levels of confidence representing the likelihood of which the observed data can result from mixing of the source data (Fig. 6).

RC 1: On L364 you say the modelling is to "more quantitatively determine the sources (sic) areas" but there does not seem to be any quantitative discussion of the model results, as far as I can tell in Section 4.2.3. It's fine if the model does not provide quantitative insights in the end, since most samples fall outside of it. But I wonder if alternative modelling approaches could be tried in this case. For example, could you not represent the floodplain endmember as the 13c-2H trend line, instead of the mean±SD value? Combined with ACL, it seems like this could yield at least semi-quantiative insights into the fraction of POMbed derived from the three different areas. Even visually, it is quite clear that HWnorth contributes very little while floodplain dominates. This seems to be obliquely alluded to in L451-459 but not actually said. And then it appears that the flux estimates are derived solely from sample concentrations in Section 5 (as far as I can tell).

AC 1: The intention of the model use is to visualize the mixing space, because we suggest a quantitively deconvolving of the sources is not possible using our geochemical data. The phrasing, hence, was misleading and we revised it. With our model correction discussed before, the mixing space, using $\delta^{13}C$

and δ^2H values increased considerably, and the floodplain leaf litter trend line lays within the mixing space. While it is still likely that the dominant control on the foreland POM_{Bed} is the foreland floodplain leaf litter composition, we would not expect a mathematically conclusive result using and end-member unmixing. Thus, the flux estimates in Section 5 are derived from the sample concentrations.

(L 443) In the previous section, we concluded that POM_{Bed} is a heterogenous mixture of OM from various sources in the catchment. First, we aim to understand the POM_{Bed} mixing space using the source area composition of the stable carbon and hydrogen isotope composition. Eventually, we apply a model to determine the mixing space, using source area and POM_{Bed} geochemical composition. Our aim is to understand the source area of POM_{Bed}, in order to determine the transformation and fate of POM_{Bed} during long-range transit.

RC 1: Overall, the choice of symbols and colours, and especially how the legend is shown in Fig 6, makes it very hard to interpret. The legend in panles a and b implies the symbol shapes and colours are showing different things, but then looking at the actual figure, it seems there is only 3 types of shape+colour types over all? The colours should be more distinct rather than different shades of the same colour. Same applies to c and d, but there shapes should also be distinct, not just circles. Is there a reason the contour lines change colour between the panels? The linear fit is not explained in the caption, and even from the text it is not clear exactly which samples are included in the fit and which are not. The grey contours and the gery circles in panels c and d are too pale and hard to see.

AC 1: Thank you for your suggestions. We revised the plot symbols, legend and figure captions accordingly.

Figure 6: Upper panels: Headwater and floodplain leaf litter and POM_{float} samples, average ± standard deviation, depicted as potential POM_{Bed} sources, using (a) nC_{29} δ^2H versus nC_{29} $\delta^{13}C$ and (b) nC_{29} δ^2H versus $ACL_{25\text{-}33}$. Lower panels: Greyed out area symbols and colored averages correspond to the OM sources from panels a and b. Colored symbols are POM_{Bed} samples from headwaters and floodplain, for (a) nC_{29} δ^2H versus nC_{29} $\delta^{13}C$, and (b) nC_{29} δ^2H versus $ACL_{25\text{-}33}$. Colored lines are probability contours of the simulated mixing area (Smith et al., 2013a), using the organic matter source. Outermost contour represents the 5%, innermost contour the 95% confidence level. Labelled POM_{Bed} samples are those that fall outside the mixing area and the source area of both plots. Uncertainty is plotted inside the symbol. Linear regression in plot a and c was conducted using lowland leaf litter data.

Technical comments

RC 1: L103: “is a braided”, word missing

AC 1: We have rephrased the sentence

Just after the headwater confluence, the lowland Bermejo exhibits a braided morphology, with river width varying from 1-3 km.

RC 1: 163: “The sampling in these earlier campaigns were performed under qualitative aspects” – unclear what you mean here, perhaps rephrase

AC 1: We have rephrased the sentence.

(L165) The sampling in these earlier campaigns were performed for the qualitative assessment of POM_{Bed} occurrence and cannot be used to quantitatively estimate POM_{Bed}.

RC 1: Fig1: it is hard to distinguish the lightest colours, especially when printed, esp soil and suspended sediment samples. The colourbar of panel b does not seem to match the map at the lightest end, ie. 0 looks much darker in the colour bar than on the map? Potentially this has to do with the hillshading. I would suggest removing the hillshading in panels b and c, or making it much lighter. Panel labels a, b, c, are too small and hard to see here, and in a number of the other figures.

AC 1: Adjusted

RC 1: Section 3 title "Analysis and preliminary data" is somewhat confusing. I would think "Methods" or "Analysis and data treatment" or similar would be suitable and more intuitive.

AC 1: We changed to section title according to the suggestion

3 Methods: Analysis and data treatment

RC 1: L198: please provide more detail on the ADCP deployment from bridges. Was it floating on a boyant board, being dragged by a rope? How did you manage to do this upstream of the bridge, rather than downstream, without it being pulled under the bridge? I think useful for the readers interested in this.

AC 1: We added more detail on the ADCP field measurements.

Surveys were conducted from bridges using an Acoustic Doppler Current Profiler (ADCP; Sontek RiverSurveyor RS-M9). The ADCP was floating on a buoyant board and towed by a rope from the bridges. We applied strong tension to the rope in an effort to prevent the ADCP from being submerged under the bridge. Where possible, the ADCP was assisted by a person in the water.

The ADCP raw data was processed using the SonTek RiverSurveyor Live Software (Version 4.1).

RC 1: Fig 2 panel a: there is some "colouring outside the lines" going on

AC 1: Adjusted the Figure

RC 1: There is a number of issues in the bibliography, with some references not formatted, or weirdly formatted. See L670, 674 for examples. It is also very difficult to tell where one ends and another begins as there's no spacing between them (not an issue in the final paper but important for reviewers).

AC 1: Thank you for this comment. We fixed the format of the indicated references, and added line breaks between the references to improve the readability.

RC 1: L245 – should paragraph break take place at the end of the sentence here, rather than at the next sentence? Makes reading this part a bit confusing.

AC 1: Thank you for the suggestions. We changed the paragraph structure accordingly.

> $\Sigma C_{25\text{-}33odd}$ is the sum of the concentration of odd-chained *n*-alkanes with chain lengths between 25-33, concentration, $\Sigma C_{24\text{-}32even}$ the sum of the concentration of even-chained *n*-alkanes with chain lengths between 24-34, and so forth.
>
> To measure compound-specific hydrogen and carbon isotope ratios of the *n*-alkanes (expressed as δ^2H, $\delta^{13}C$ values), we used a Trace GC 1310 (ThermoFisher Scientific) connected to Delta V plus Isotope Ratio Mass Spectrometer (IRMS) (ThermoFisher Scientific) following the procedures described by Rach et al. (2020). *n*-alkane δ^2H and $\delta^{13}C$ values were measured in duplicates. For each sample run, we measured the *n*-alkane standard-mix A6 (with n-alkane chain lengths ranging from *n*C16-*n*C30) with known δ^2H values obtained from A. Schimmelmann (Indiana University), for correction and transfer to the VSMOW scale.

RC 1: Fig 3 / L262-263 – the R2 values don't match the figure. Or if it's a regression of a different set of samples, that is not clear from the text. Also some figure panel references are wrong.

AC 1: Thank you for the comment. The R2 values in the figures did not correspond to the linear regression in the text. We changed respective text paragraph to match the figure and the R2 of the regression. We also adjusted the figure panel reference

> We measured the δ^2H and $\delta^{13}C$ values for the dominant chain lengths, nC_{29} and nC_{31}. Because these *n*-alkanes showed a significant correlation for $\delta^{13}C$ ($R^2 = 0.95$) and δ^2H values ($R^2 = 0.81$, Fig. 3g, h), we will focus on the nC_{29} values.

RC 1: Fig 4: the open symbols are difficult to see, especially the paler ones. Consider thicker lines, stronger colours.

AC 1: Thank you for this suggestion. We adjusted the symbol line thickness accordingly.

> Figure 4: Examples of captured POM_{Bed} as (a) bulk fraction from the Southern Tributary at Pichanal, (b) Rio Bermejo at Puerto Lavalle, in particle size separates: >1 mm, aggregated (left) and dissociated (middle), and <1 mm mixed with clastic material, (c) bulk at the upper Rio Bermejo at Embarcacion, and (d) sampled bulk bed material (empty symbols) and POM_{Bed} > 1 mm (filled symbols) per sampling point at all sampling locations. Superscript denotes sample origin from [1] Southern tributary, [2] Northern tributary and [3] Floodplain. Note the

unequal x-axis breaks, and that POM_{Bed} > 1 mm is shown in in g min^{-1}, and bulk bed material in in g min^{-1} $x10^{-1}$, to account for the mass difference of the samples.

RC 1: L325-328: "POMBed CPI25-33 values (average: 7.4±3.0, n = 39) were not significantly different from… soils" followed by, "on average POMBed CPI25-33 values were lower than soils…"

AC 1: Thank you for the observations! We corrected the phrasing.

POM_{Bed} CPI_{25-33} values (average: 7.4±3.0, n = 39) were not significantly different from leaf litter (7.4 ±4.0, range:1.0-19.8, n = 28) and river bank sediments (6.5±3.7, range: 0.3-13.7, n = 18). However, on average POM_{Bed} CPI_{25-33} values were significantly higher than from soils (5.9±3.6, range: 0.2-16.3, n = 29) and suspended sediments (5.5±1.0, range: 1.1-7.8; n = 41), indicating a lower maturity of POM_{Bed}.

RC 1: Fig 5: panels c and d mixed up in the caption

AC 1: We adjusted the caption.

Figure 5: Summary of (a) ACL_{25-33}, (b) CPI_{25-33}, (c) nC_{29} $\delta^{13}C$ and (d) nC_{29} $\delta^{2}H$ values of POM_{float}, headwater and floodplain leaf litter; POM_{Bed} from the northern headwater, southern headwater and downstream floodplain; floodplain soil, bank sediment, and suspended sediment. Boxplot width shows the interquartile range, black line the median, whiskers minimum and maximum range of the data without outliers. Black dots indicate outliers with 0.75 Quantile + 1.5 x interquartile range and 0.25 Quantile - 1.5 x interquartile range, respectively.

RC 1: Section 4.2.1 – it would seem more logical to place this after what is now section 4.2.2 – this is also because Fig 6 is really properly explained only in section 4.2.3

AC 1: Thank you for this suggestion. We placed section Section 4.2.1 and after Section 4.2.2.

The new sectioning is now: 4.2.1 Biomarker stable isotope insights into POM_{Bed} source areas; 4.2.2 Mixing model analysis; 4.2.3 Mixing model insights into POM_{Bed} source areas. To that effect, we switched the positions of Figure 6: Mixing Model and Figure 7: Sampling elevation regression, to Figure 7: Mixing Model and Figure 6: Sampling elevation regression

RC 1: I would encourage supplying the code that was used for the endmember mixing model in the supplementary material.

AC 1: We added the adapted code from Smith et al, 2013 and the used data input to the supplement.

RC 1: L378 – what is a "resolution of 500" in this case?

AC 1: The resolution refers to grid of the initially defined mixing space where the point-in-polygon assumption is tested. The grid borders are defined as minimum and maximum extent of the variables used. A resolution of 500 hence, means that the point-in-polygon assumption is tested on a grid of 500 x 500 points within the initial mixing space. We added this explanation to Section 4.2.2.

RC 1: L434, the linear trend equation and R2 value does not match the one shown in Fig 6.

AC 1: Thank you for this comment! The linear trend equation in Fig. 6 was indeed performed on different data ($\delta^{13}C$, $\delta^{2}H$). We added the correct equation to the figure.

RC 1: L436-437: this sentence is unclear. Floodplain leaf litter is an important source of POMbed but is not mixed into the bedload? seems contradictory

AC 1: The concept behind this statement is that floodplain leaf litter is a source for bedload. However, during the formation of bedload by floodplain leaf litter (water-logging and sinking), the newly formed POM_{Bed} does not mix with the existing POM_{Bed}. We formulated the statement accordingly, to clarify this point.

> The spread in geochemical proxies of POM_{Bed} suggests that this newly, lowland-derived plant material is in large parts not yet mixed within the already existing bedload sourced from upstream areas, and hence, dominantly resembles local floodplain leaf litter input.

RC 1: L439 – “downstream trend” – please rephrase for clarity. Is there an actual trend going downstream from site to site, or do you mean a trend AT the downstream sites.

AC 1: This paragraph was intended to draw attention to the fact that there is no altitudinal trend in $\delta^{2}H$ values in floodplain leaf litter. By saying an altitudinal effect within the lowland floodplain can be excluded due to the low relief, the light $\delta^{2}H$ values must indicate a headwater source of POM_{Bed}. However, this statement is not necessary for the argument. To avoid confusion, we removed it.

RC 1: Fig 7 – has the same issue with the legend as Fig 6

AC 1: We adjusted the legend.

RC 1: L449 – should be “land use” not “land consumption”

AC 1: Changed.

> We suggest that the missing source in our samples is farmland OM, which would indicate that the POM_{Bed} carbon flux can be directly influenced by anthropogenic land use.

RC 1: L467 – "flow structures" perhaps, rather than "flow motions"

AC 1: Changed to "flow motions".

> We attribute occasionally negative flow velocities to local flow motions large river bedforms (Allen, 1968),

RC 1: L498 – should it say "values ONLY as high as 7.8"? because it seems the point you're making is that these values are low, compared to POM_{Bed}

AC 1: Thank you for the comment! We adjusted the sentence.

> River suspended sediment samples yielded similar CPI_{25-33} values, on average 5.5±1.0 (range: 1.1-7.8; n = 41), but with less variability and values only as high as 7.8, suggesting advanced mixing and maturity compared to POM_{Bed} (average: 29.6±0.9, range 27.4-31.6, n =39).

RC 1: Equation 3 – why are you using the funnel width, as opposed to cross sectional area? Presumably the implied assumption is that POMbed transport occurs in a tin layer near bed that is less than 8cm, ie the vertical dimension of the opening of your sampler? If so, it would be good to explicitly say this. Could you ponentially be underestimating the flux if the POMbed is transported in a thicker layer, saltating, etc?

AC 1: Thank you for the suggestion! The implicit assumption is that bedload transport is limited to 50% of the channel and up to 8 cm above the river bed. With our data set, is not possible to know the actual extent of the bedload load in width and particularly in height. This simplification surely underestimates the POM_{Bed} flux in the vertical dimension. In addition to the fine POM_{Bed} fraction <1mm that we do not consider, we are missing two central components with our estimation: (1) Coarse organic debris > 8 cm that exceeds the funnel opening, and (2) Coarse organic debris that moves saltating and temporarily exceeds the height of the funnel opening. These two components could be an additional substantial bedload component. We clarified the implicit assumption and potential underestimation within Section 5.

> Our approach assumes that the dimension of the POM_{Bed} layer, and its individual particles are within the constraints of the funnel height of the sampler, and that the samples and sampling points across each transect accurately represents the entire cross-section of the channel. A larger samples size, and sampled surfaces area, longer sampling times, and better understanding of distribution and dynamics of the POM_{Bed} layer could greatly enhance the accuracy of the sample set and flux estimates.

RC 1: L518 – could you not estimate %OC of your own samples from your analyses? And/or explain briefly what the "van Bemmelen factor" is

AC 1: The van Bemmelen constant assumes that pure (soil) organic matter contains 58% of organic carbon. The measurements of %OC refers to the total sediment mix, including the clastic and organic sediment, and hence, likely gives an underestimated of the OC that is contained in the organic fraction only. We added a short explanation to the van Bemmelen factor.

We estimated the carbon content of POM_{Bed} to be 58% organic carbon, using the van Bemmelen factor, a conversion factor to estimate the carbon content in (soil) organic matter (Allison, 1965).

RC 1: L522 – it would be more meaningful to give the length of the wet season in days rather than seconds

AC 1: Done.

Since we did not capture significant amounts of POM_{Bed} during the dry season, we assumed that POM_{Bed} transport only occurs during the six months of the high flow season ($t_{transport}$ = 182.5 days) to estimate the POM_{Bed} flux in tC yr^{-1}.

RC 1: L524 – sentence unclear, potentially some words missing

AC 1: Restructured the sentence for clarity.

HW_{North} and HW_{South} both show an increase in the POM_{Bed} flux from the upper headwater locations ($HW_{North-2}$ and $HW_{South-2}$, respectively) to the lower headwater locations ($HW_{North-1}$ and $HW_{South-1}$, respectively), demonstrating the possibility of fast recruitment of POM_{Bed} on short distances.

RC 1: Table 2 – caption is very difficult to comprehend and does not seem to reflect the table contents. For a number of samples "n" is the overwhelmingly more common convention rather than "i". Is "total bedload (g) the average of the samples, or total sum of all samples? Why is this meaningful to show, compared to g/s? Water flow rates should be included here.

AC 1: We changed the "number of samples n" to the variable we used in the equation: "$t_{sampling}$ in min", which corresponds to the number of samples used. We adjusted the title of "total bedload (g)", to "total sum bedload (g)", and we removed the flux in g/s, since this is easily to be derived from the information already given in the table. We additionally added the near-bed flow velocities, where available. We further considered the suggestions of referee 2 and adjusted the nomenclature and caption of Table 2.

Table 2: Bedload sampling locations and yields from the field campaign in 2020, and estimated flux of particulate organic carbon on the river bed.

Location name	Sampling time $t_{sampling}$	Total sum bedload	Total sum POM_{Bed} >1 mm	Full transect width	Average near-bed flow velocity ± standard deviation [a]	POC_{Bed} flux ± standard deviation [c]
	(min)	(g)	(g)	(m)	(m s^{-2})	(tC yr^{-1})
$HW_{South-2}$ (Caimancito)	2	588	22	80	NA	855 ± 513
$HW_{North-1}$ (Embarcacion)	4	2589	5	169	0.29 ± 0.3	150 ± 38
$HW_{South-1}$ (Pichanal)	11	7283	66	183	0.49 ± 0.3	1032 ± 106
$HW_{North-2}$ (Rio Colorado)	4	955	3	35	NA	11 ± 1
LL_{-1} (Puerto Lavalle)	7	617	9	215	-0.19 ± 0.4	253 ± 98
LL_{-2} (El Colorado)	5	617	1	90	0.27 ± 0.6	23 ± 4

[a] Measured using ADCP. [b] Averaged per number of samples per sampling site. [c] Calculated using Equation 3.

RC 1: L564 – "ad this eye-catching feature" – I would suggest rephrasing, it is not clear if you're referring to POMbed transport or something else here.

AC 1: We rephrased the paragraph for clarity.

> While our bedload carbon flux estimates are tentative, it is clear that this eye-catching mode of organic carbon transfer is small in comparison with the fluvial export of organic carbon in the suspended load of the Rio Bermejo. Nevertheless, the Rio Bermejo's suspended sediment yield is exceptionally high (Sambrook Smith et al., 2016), and POM_{Bed} in rivers and sedimentary deposits could contribute substantially to the overall flux in other river systems with lower suspended sediment yield (Turowski et al., 2016), and in highly erosive headwater streams with short transport distances from recruitment to subsequent deposition and burial (Blair and Aller, 2012; Hilton et al., 2011).

Referee 2

General Comments:

Sourcing and long-range transport of POM in river bedload: Rio Bermejo, Argentina

I have read over the other reviewers' comments, so I have not added some of those in this review but do encourage the authors to address his thorough comments. This is a very interesting paper, with a lot of samples ranging from various years, and previous studies, taken in a remote location. A continuation of engaging and interesting studies that comes from this region of the world and from this research group.

Interesting method to sample the near bottom of the river (POM_{bed}), and an area of the river that is important but neglected. Sampling focused on smaller particles, would large woody debris be an element to consider, as this often flows fast but along the riverbed (i.e. Peruvian foothills). Regardless, since this type of measurement is new, I recommend explaining clearly what it actually is measuring (i.e. the material flowing along the riverbed, rather than buried in the riverbed).

Well explained mechanisms of river POM recruitment and transport. The results and discussion are well written, and easy to read and follow.

You carried out this study during a very challenging time (Covid-19 Pandemic), which is commendable.

AC 2: Thank you for your comment and suggestions. Larger woody debris would certainly be another interesting element to sample. Unfortunately, our sampling design did not consider large woody debris bedload transport. We clarified the material we define and sample as POM$_{Bed}$ in this study in more detail.

> (L199) For our purpose, we define POM$_{Bed}$ as organic material that is entrained within the clastic bedload, transported as separate layer on top of the clastic bedload, or that moves close to the river bed. It is likely that the POM$_{Bed}$ material is transported in a more extensive layer above the bed (Repasch et al., 2022; Schwab et al., 2022) also including saltating trajectories (Einstein et al., 1940; Turowski et al., 2010). The maximum particle size of the bedload samples was likely limited by the funnel opening width of 8 cm, as has been demonstrated for clastic bedload (Bunte et al., 2008), and our sample collection was restricted to the material transported within 8 cm above the bed.

Specific comments:

RC 2: Section 4.1.1 Flux of g/min appears in the text, but how are you calculating a POM$_{bed}$ flux from a grab sample? Explain please.

AC 2: We only used the data from the 2020 sampling campaign where we sampled with a Helley Smith Sampler. The flux in Section 4.1.1 is estimated using solely the mean of all 1-Minute samples per location. In this section, we do not project the flux through the river cross-section or discharge. We added a clarifying sentence.

> The sampling in these earlier campaigns was performed for the qualitative assessment of POM$_{Bed}$ occurrence and corresponding data were not used to quantitatively estimate POM$_{Bed}$.

RC 2: In Section 5, you do a good job to estimate fluxes, but do you think it would be good to include more on limitations (i.e. some sites only had one sample), how might the sampling have been improved. It is understandable that you were limited because of Covid. It is amazing that you were able to do any sampling at all during this time.

AC: Thank you for your comment and feedback! We added some more discussion on limitations into section 5.

> Higher agricultural activities in HW$_{South}$ could also enhance surface erosion, and with that OM input locally. Our approach assumes that the dimension of the POM$_{Bed}$ layer, and its individual particles are within the constraints of the funnel height of the sampler, and that the samples and sampling points across each transect accurately represents the entire cross-section of the channel. A larger samples size, and sampled surfaces area, longer sampling times, and better understanding of distribution and dynamics of the POM$_{Bed}$ layer could greatly enhance the accuracy of the sample set and flux estimates.

Technical comments:

RC 2: L66: check spacing

AC 2: Spacing adjusted

Several studies describe fresh, coarse terrestrial organic debris transported to delta plains (Allen et al., 1979) and offshore (West et al., 2011) by turbidity currents (Hage et al., 2020; Liu et al., 2013; Tyson and Follows, 2000).

RC: L106-107: check sentence structure

AC 2: We adjusted the sentence structure

The channel width narrows to 170 m in the most downstream parts, towards the confluence with the Rio Paraguay (Repasch, 2023; Repasch et al., 2020; Sambrook Smith et al., 2016). This is where our downstream floodplain samples were captured.

RC: L112: SS and bedload sediment make this yield?

AC 2: The reported yield only comprises the suspended load. We clarified this in the text

The Rio Bermejo delivers ~80 Mt yr^{-1} of suspended sediment to the Rio Paraguay. Suspended sediment input from the Andean headwaters at the Bermejo-San Francisco confluence is significantly higher, ~103 Mt yr^{-1}, suggesting net deposition during foreland transit (Repasch et al., 2020).

RC 2: Table 1 caption is very long, do you need to include all the variables in the caption?

AC 2: We shortened the caption of Table 1

Table 1: Overview of the bedload sampling sites, location, number and type.

RC 2: L151: roughly what was a sufficient sample you collected in the field? If only 1 gram of OM isolated, would this be an area for improvement in the future? Or a study limitation?

AC 2: The questions of sufficiency depend on the goal of the sampling. Our primary goal was chemical analysis (compound-specific stable isotope composition) that needs a concentration of XX *n*-alkanes for the analysis. Hence, 1 gram of isolated OM can be sufficient, if the individual samples contain a sufficient concentration of *n*-alkanes. However, if the sample is sufficient for analysis cannot be known during field sampling, but after extraction in the lab. A bigger sampling amount within all samples (> 10 g of organic matter) possibly would have permitted further analysis, such as grain sizes distributions, which would have added interesting information to the study.

The sampling could be improved, for instance through longer sampling times and wider sampling area on the river bed. However, this imposes additional difficulties, particularly within a relatively turbulent and deep river that the Rio Bermejo is, and is indeed a main reason why field studies considering bedload transport are challenging overall. The sampling technique and amount hence, may indeed, contain limitation. For instance, bedload transport is not continues, hence, one-minute samples are only snapshots of transport that not necessarily represent the total variability in amount and composition of the bedload. The same is true for the relatively small sample amount and sampled area compared to the river cross width.

> We additionally collected bedload samples at one location per sampling site for a longer period, usually around 5 minutes, to attempt the collection of a sufficient amount of organic bedload material for compositional analysis.

RC 2: L166: spacing

AC 2: Spacing added

> The maximum size of the bedload samples was likely limited by the funnel opening width of 8 cm, as has been demonstrated for clastic bedload (Bunte et al., 2008) and limits our sample collection to the material transported within 8 cm above the bed,

RC 2: L165: I would make it clear what you mean by POM_{bed}, because I would have thought it was POM in the riverbed, rather than 8cm above the bottom.

AC 2: We added some description regarding the definition of POM_{Bed} in our study.

> For our purpose, we define POM_{Bed} as organic material that is entrained within the clastic bedload, transported as separate layer on top of the clastic bedload or moves close to the river bed. It is likely that the POM_{Bed} material is transported in a thicker layer above the bed (Repasch et al., 2022; Schwab et al., 2022). However, due to the variable transport trajectories of bedload transport, POM_{Bed} may move saltating on the river bed (Einstein et al., 1940; Turowski et al., 2010).

RC 2: L178: are there any study limitations by not measuring POM_{float} in the northern tributary? Do you expect it to be consistent with the south tributary?

AC 2: Our results suggest that the southern tributary POM_{float} is not a significant source to the POM_{Bed} and we suggest that this is similarly for the northern tributary. Hence, there should not be significant limitations by not measuring the northern tributary POM_{float}. Yet, as our results indicate, we do miss at least one source of the $POM_{Bed,}$ which may be northern headwater POM_{float}. However, we suggest that the significant amount of large woody debris along the headwater and the downstream catchment, seems more plausible to be a quantitatively important source to the POM_{Bed}. Allover, not being able to constrain all the source to the POM_{Bed} does impose limitations to the study. However, the main statement, a small amount of POM_{Bed} persists long-distance transport, while most POM_{Bed} is accumulated during transport, remains as it is.

We collected seven samples of floating, coarse particulate organic matter (POM_{float}, > 1 mm) along the Rio San Francisco (one at 313 m asl and another at 2458 m asl) during the high flow season in March 2013 (Fig. 1a).

RC 2: L281: Section 4 appears, is there any distinction between materials and methods and results? Check journal specifics.

AC 2: We changed the title of Section 3 to Methods: Analysis and data treatment, following the suggestion of Referee 1. We use section three to report raw results, because the following analyses are based on the findings of the raw results. These are, for instance, the preliminary analysis of two size fractions (bigger and smaller 1 mm) with subsequent usage of the samples as bulk, and the sole usage of the *n*C29 *n*-alkane. We added a paragraph "3.2.1 Organic-geochemical raw results", before reporting these results. Within section 4, we continue to describe the results with subsequent discussion for each subsection.

RC 2: L297: is there a correlation with velocity near the riverbed?

AC 2: There was no correlation with either clastic or organic bed material and average near-bed velocity. We added this information.

The mass of organic bedload scaled loosely with the amount of clastic sediment collected (Fig. 4d), but there was no correlation with sampling material and near-bed velocities.

RC 2: Figure 4 a-c, really nice visuals of the samples

AC 2: Thank you!

RC 2: Figure 6, POM_{float} in the legend needs fixing, too much space.

AR 2: Space in Figure 6 adjusted.

RC 2: L482: spacing needed

AR 2: Spacing added.

Episodic flushing events of the channel can transport parcels efficiently (Heijnen et al., 2022), and facilitate waterlogging of the organic debris (West et al., 2011).

RC 2: L494: What about average particle size within the samples?

AR 2: We refrained from specific particle size measurements within the samples based on two reasons: First, the total sample amount varied widely, and hence, to serve the purpose of a source analysis using geochemical methods, we did not want to contaminate the limited sample amount available and thus, carried out the dry sieving for the fractions bigger and smaller than one millimeter, and a visual analysis of the size trends with downstream sampling locations. We added an explanatory sentence in Line 317.

We refrained from measurement of the average particle size within each sample, to secure sufficient sampling material for geochemical analysis, but there was a visible reduction in grain size from the headwater to the downstream locations (Fig. 4).

RC 2: Table 2 caption is very long. Check that you're happy with this, otherwise maybe it can be simplified, or some content can move to a footnote.

AR 2 / AC 1: Thank you for the suggestion. We adjusted the nomenclature and caption of Table 2, considering the suggestions of referee 1 and added the near-bed flow velocities, where available.

Table 2: Bedload sampling locations and yields from the field campaign in 2020, and estimated flux of particulate organic carbon on the river bed.

Location name	Sampling time $t_{sampling}$	Total sum bedload	Total sum POM_{Bed} >1 mm	Full transect width	Average near-bed flow velocity ± standard deviation [a]	POC_{Bed} flux ± standard deviation [c]
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[a] Measured using ADCP. [b] Averaged per number of samples per sampling site. [c] Calculated using Equation 3.

Literature

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