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Fluvial Organic Carbon Composition Regulated by Seasonal Variability in Lowland River Migration and Water Discharge

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Key Points:

- Discharge and river lateral migration rate set particulate organic carbon (POC) isotopic composition in a lowland river
- High lateral channel migration rates during the wet season drive replacement of headwater-sourced POC by floodplain POC
- Wet seasons account for ~85% of the annual POC export, suggesting that POC export is dominated by floodplain-sourced organic matter

Supporting Information:

Supporting Information may be found in the online version of this article.

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Abstract

Identifying drivers of seasonal variations in fluvial particulate organic carbon (POC) composition can aid sediment provenance and biogeochemical cycling studies. We evaluate seasonal changes in POC composition in the Río Bermejo, Argentina, a lowland river running ~1,270 km without tributaries. Weekly POC concentration and isotopic composition from 2016 to 2018 show that during the wet season, increased lateral channel migration generates an influx of ^{13}C-enriched and ^{14}C-enriched floodplain-sourced material, overprinting the ^{13}C-depleted and ^{14}C-depleted headwater signature that is observed during the dry season. These findings demonstrate how channel morphodynamics can drive variability of POC composition in lowland rivers, and may modulate the composition of POC preserved in sedimentary archives.

Plain Language Summary

Reconstruction of past climate conditions is often based on the chemistry of organic matter transported from rivers into ocean basins. However, it is unclear how organic matter chemistry changes from its original continental source to its final sink in ocean basins. As organic matter moves downstream through lowland rivers, this material can be deposited in floodplains. During floodplain storage, organic matter is decomposed and replaced, changing its chemistry and, ultimately the record of past climate. To understand how organic matter chemistry changes seasonally, we collected weekly samples of suspended sediment in the Río Bermejo, Argentina for two consecutive years. We measured changes in organic matter chemistry and in the rate of river bank erosion. We found that the Río Bermejo transports more organic matter sourced from mountains at periods of low flow, when the river does not erode its banks, and the river transports more organic matter sourced from floodplains during periods of high flow, when the river actively migrates. Because high flow periods account for most of the annual organic matter export, our results suggest that river-sourced organic matter in ocean basins is likely a mix of soil, sediment, and vegetation from floodplains.

1. Introduction

Burial of particulate organic carbon (POC) in sedimentary basins drives a long-term atmospheric CO_2 sink (e.g., France-Lanord & Derry, 1997) and creates paleoclimate archives (e.g., Hein et al., 2017). However, POC flux to depositional basins, and the paleoclimate conditions recorded therein, can be modulated during source to sink transit, analogous to how fluvial transport modifies environmental signals in clastic deposits (Hajek & Straub, 2017; Jerolmack & Paola, 2010). In lowland rivers, sediment exchange between rivers and floodplains can modify upstream-derived POC (Aufdenkampe et al., 2007; Galy et al., 2008; Moreira-Turcq et al., 2013; Torres et al., 2017). Floodplains store, modify, and oxidize upstream-derived POC (Bouchez et al., 2010; Scheingross et al., 2019, 2021), and floodplain vegetation provide an additional POC source (e.g., Lininger et al., 2018; Moreira-Turcq et al., 2013; Sutfin et al., 2016).

The fate of POC in lowland rivers has implications for the carbon cycle and the creation of paleoclimate archives. POC sourced from sedimentary rock (i.e., petrogenic POC, POC_{petro}) may be oxidized during floodplain

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storage and resuspension (Bouchez et al., 2010; Scheingross et al., 2021), producing a long-term atmospheric CO_2 source. However, this CO_2 source can be balanced by the long-term burial of recently produced POC (biospheric POC, POC_{bio}) sourced from channel margins and floodplains (Galy et al., 2007a). Furthermore, as paleoclimate information recorded in POC isotopic composition is often sensitive to the elevation at which POC was produced (e.g., Hoffmann et al., 2016; Ponton et al., 2014), replacement of headwater-sourced POC_{petro} with floodplain-sourced POC (including both *in situ* vegetation growth and soil development in the floodplain, and POC sourced in headwaters but modified during floodplain storage) complicates paleoclimate interpretations.

POC modification studies in lowland rivers have focused on sampling material transported at high discharges (e.g., Aufdenkampe et al., 2007; Bouchez et al., 2010; Galy et al., 2008) and examination of floodplain deposits formed during high flow (e.g., Goñi et al., 2014; Scheingross et al., 2021; Torres et al., 2020). However, POC composition varies seasonally, reflecting changes in headwater erosion (Clark et al., 2017; Goñi et al., 2013; Hemingway et al., 2017; Hilton et al., 2008; Li et al., 2015; Qu et al., 2020) and river-floodplain hydrologic connectivity (e.g., Moreira-Turcq et al., 2013; Pedrozo & Bonetto, 1987). Some of this variability may be driven by channel migration, which can regulate POC composition by setting the exchange of material between the rivers and floodplains and setting the timescales of vegetation growth (e.g., Lininger & Wohl, 2019; Torres et al., 2017). No study, to our knowledge, has explicitly explored the interplay between channel migration and seasonal variation in POC composition.

We hypothesize that the relative proportion of floodplain-sourced versus headwater-sourced POC in lowland rivers depends on channel migration rate and channel length, as lateral migration allows erosion of floodplain-sourced POC while headwater-sourced POC is deposited. This should lead to seasonal variability in POC composition. At high flow, lowland rivers should preferentially export floodplain-sourced POC due to increased channel migration rates (Constantine et al., 2014) and overbank flow, while at low flow, reduced channel migration rates limit bank erosion, allowing a greater representation of headwater-sourced POC (including POC_{petro}) in the river load. We test this hypothesis via analyzing POC composition for 2 years of suspended sediment in the Río Bermejo, Argentina.

2. Study Site

The Río Bermejo, Argentina drains the central Andes, and has headwaters underlain by Paleozoic marine and Cenozoic terrestrial sedimentary rocks (McGlue et al., 2016). At the mountain front, the Río San Francisco (RSF) joins the Río Bermejo to form the "Lowland Bermejo" (Figure 1), which runs ∼1,270 km to the Río Paraguay with no tributary inputs (a paleochannel, the Río Bermejito, contributes <2% and <0.02% of Lowland Bermejo water and sediment discharge, respectively (Orfeo, 2006; Argentina National System of Hydrologic Information, *SNIH*, Figure 1). Both the Río Bermejo headwaters and lowlands have predominately C_3 vegetation (Powell & Still, 2009, Figure 1b). The Bermejo headwaters (drainage area of 1.2×10^5 km^2) and lowlands receive ∼1,200 mm/yr and ∼700 mm/yr precipitation, respectively (Harris et al., 2014), resulting in mean annual water discharge (Q_w) and sediment flux of 432 m^3/s and ∼80 Mt/yr, respectively. River discharge and suspended sediment flux from January to April average ∼750 m^3/s and ∼410 kt/day in the Lowland Bermejo, respectively, ∼5 times greater than average discharge and sediment flux during the June to December dry season of ∼150 m^3/s and 15 kt/day, respectively (Figure 2) (Alarcón et al., 2003; Cafaro et al., 2010; Drago & Amsler, 1988; Repasch et al., 2020; *SNIH*). The Lowland Bermejo migrates across its floodplain at rates of ∼6–23 m/yr, and experiences periodic avulsions (Page, 1889; Repasch et al., 2020). This exchange between the active river channel and its floodplain results in an average sediment transit time of ∼8.4 ± 2.2 ky across the Lowland Bermejo (Repasch et al., 2020).

Organic matter in the Río Bermejo is sourced primarily from erosion of sedimentary bedrock, soil, floodplain sediment, and vegetation (Scheingross et al., 2021); high turbidity minimizes aquatic primary production (Pedrozo & Bonetto, 1987). POC_{petro} concentrations in Lowland Bermejo suspended sediment are low (∼0.01–0.04%) relative to the total POC concentration (∼0.01–1%), with no detectable downstream POC_{petro} changes (Scheingross et al., 2021). Analysis of an ∼20 ky chronosequence of Lowland Bermejo floodplain sediments (up to 4.9 m depth) shows a systematic ^{13}C enrichment in POC with floodplain storage time, but no systematic variation in radiocarbon composition or nitrogen to carbon (N/OC) ratios (Scheingross et al., 2021).

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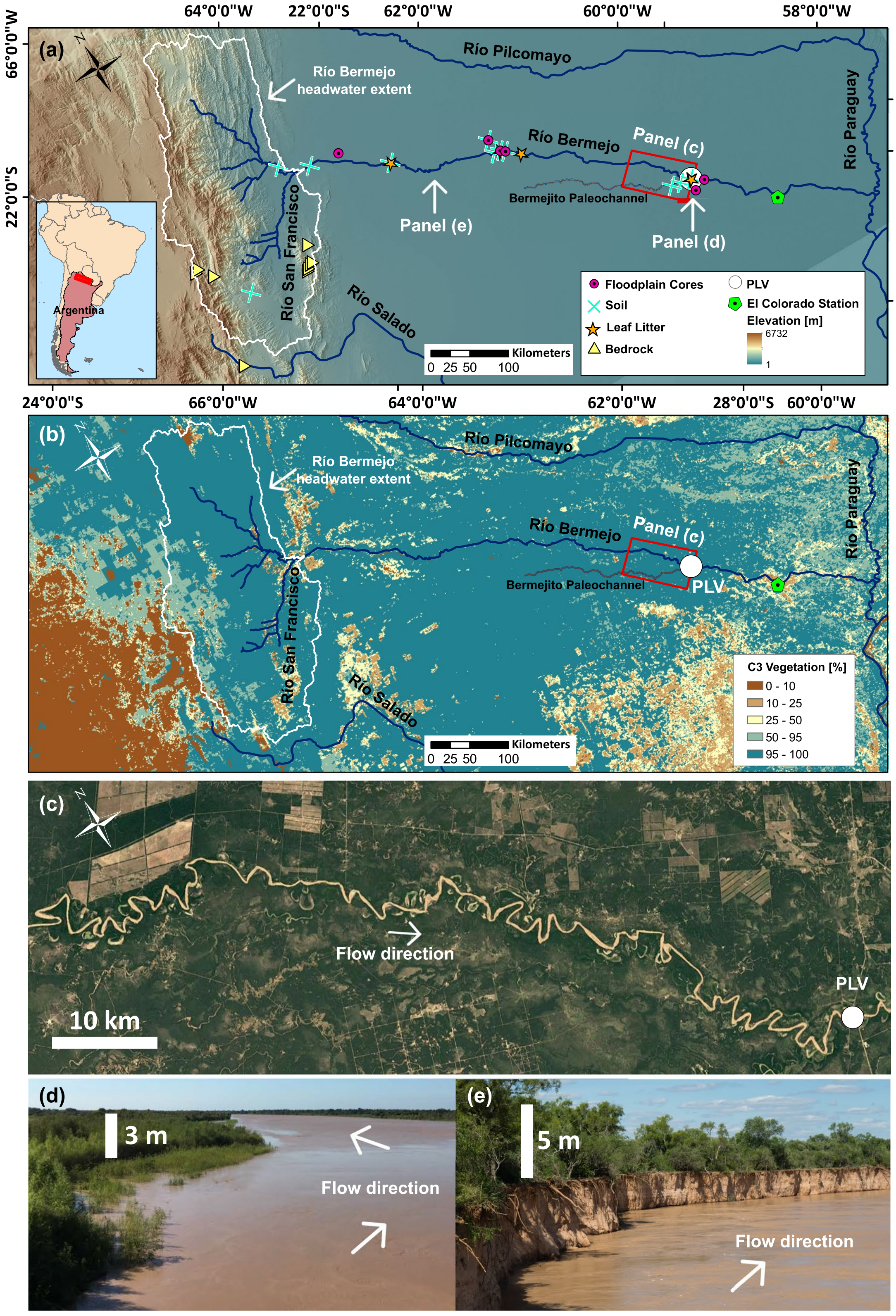

Figure 1. (a) Río Bermejo sampling locations. Red box denotes the area of channel migration rate measurements and corresponds to the panel (c) spatial extent, inset shows regional location. (b) C_3 vegetation percent (Powell et al., 2012). (c) Satellite imagery showing oxbow lakes and active channel migration. (d, e) Photos at Puente Lavalle (PLV) and ~450 km upstream of PLV, respectively.

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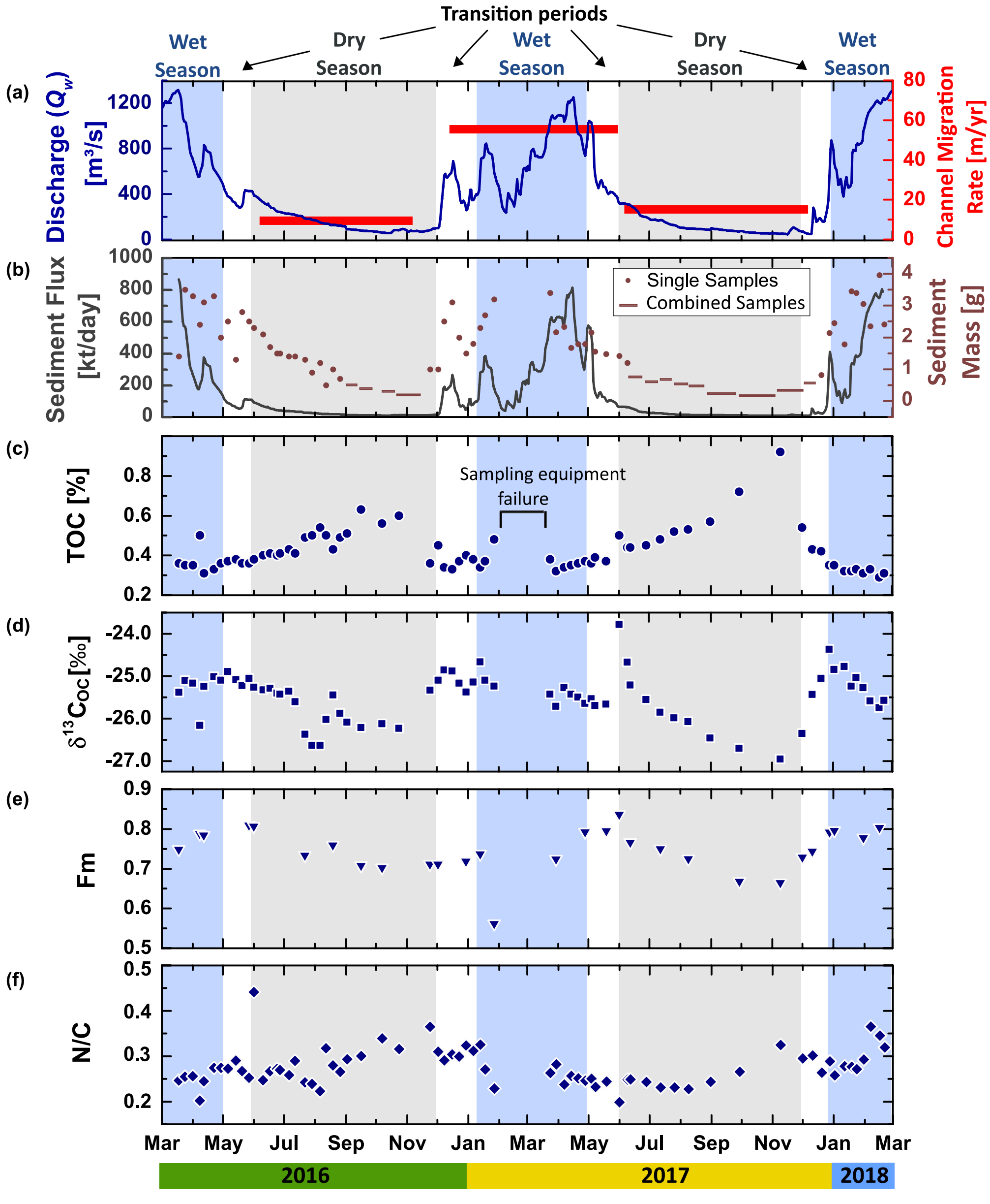

Figure 2. Temporal variation of (a) water discharge (measured at El Colorado by *SNIH*) and channel migration (bar length represents the time between satellite images), (b) sediment flux and mass collected, dots and lines represent single and amalgamated samples, respectively (Supplementary Text), (c) total organic carbon (TOC), (d) $\delta^{13}C_{OC}$, (e) Fm, and (f) N/OC.

3. Methods

3.1. Sample Collection

We evaluated POC temporal variability via collecting weekly suspended sediment samples (March 2016 to March 2018) at Puente Lavalle (PLV), ~870 river km downstream of the mountain front (Figure 1 and Table S1). We collected surface water samples (from a bridge using a river-rinsed bucket) to assess temporal POC variability without added complications due to POC variability with water column depth (e.g., Bouchez et al., 2014). Samples were filtered through a 0.22 μm polyethersulfone membrane, placed in *Whirl-PAK* bags, and stored on site at ambient temperatures for <1 year in a sealed, opaque box (with no visible mold growth), before transfer to Germany and storage at ~4 °C.

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To document distinct POC sources, we collected 15 soil and 13 leaf litter samples (predominantly C_3 vegetation) from the Lowland Bermejo basin, and 10 bedrock (predominantly silt and mudstones) and 2 soil samples from the Río Bermejo headwaters (Figure 1 and Table S2). We collected leaf litter (at the ground surface) and soil (<5 cm from the ground surface) using an ethanol-rinsed trowel. We supplemented these samples with existing Río Bermejo floodplain sediment cores and headwater suspended sediment (Scheingross et al., 2021; Table S2).

3.2. Analytical Methods

We rinsed suspended sediment samples from filters into precombusted glass evaporating dishes using ultrapure (18.2 MΩ) water. Samples were oven-dried at 40 °C for >48 hr and we manually removed plant matter >1 cm. We homogenized suspended sediment and soil in an agate mortar without crushing, shredded leaf litter in a blender, and pulverized bedrock in a disc mill. Geochemical and grain size analyses required >0.8 g sediment; for samples <0.8 g, we combined consecutive weekly suspended samples to create a combined sample of >0.8 g (Table S1).

We split samples into aliquots for grain size analysis via laser diffraction (Supplementary Text) and geochemical analyses, and ground the latter to <63 μm. We further split the homogenized suspended sediment, bedrock, soil, and leaf litter aliquots for total nitrogen measurement (TN, wt %) and organic carbon analyses including total organic carbon (TOC, wt%), stable carbon isotope composition ($\delta^{13}C_{OC}$), and radiocarbon fraction modern (Fm). We decarbonated the aliquots for POC measurements using a liquid HCl leach (Galy et al., 2007b). TOC and TN were measured with an elemental analyzer (EA), and $\delta^{13}C_{OC}$ measured with a coupled EA-isotope ratio mass spectrometer (Supplementary Text). Radiocarbon was measured for 29 samples with an EA coupled to an accelerator mass spectrometer (McIntyre et al., 2017; Supplementary Text).

3.3. Channel Migration Rates

We measured lateral channel migration along a 140 km reach upstream of PLV (Figure 1c), which is the average distance required for the suspended load to be replaced with floodplain material via channel migration during high flow (Supplementary Text). We used Sentinel-2 and Planet satellite images (10 and 3 m resolution, respectively) to measure channel migration rates (Supplementary Text and Figure S1). We calculated the average lateral migration rate (E_{lat}) as (Torres et al., 2017):

$$\boldsymbol{E_{lat}} = \left(\frac{\boldsymbol{A}}{\boldsymbol{L} \times \boldsymbol{t}}\right) \tag{1}$$

where A is the eroded area measured from satellite images, L is channel length along which erosion was measured, and t is the time between images (estimated error of ~2 pixels which is ~20 m and equivalent to ~5–13% of the 150–400 m wide channel).

3.4. Data Analysis

We separated the wet and dry seasons at Q_w = 400 m³/s, based on the maximum observed dry season discharge in the study period and previously documented changes in the relation between suspended sediment flux and discharge (Alarcón et al., 2003, Figure 2). We quantified seasonal variability in POC composition by evaluating linear correlations between water discharge (Q_w) and TOC, $\delta^{13}C_{OC}$, Fm, and N/OC (wt %/wt %), for both the wet and dry seasons. We assessed statistical significance (defined at $p < 0.05$) using the Pearson correlation coefficient, ρ, where $\rho = 1$ and $\rho = -1$ for perfectly monotonic positive and negative correlations, respectively. We additionally tested for statistical differences between the populations of values in the wet and dry seasons using a two-sample Kolmogorov-Smirnov test (Massey, 1951).

We performed mixing analyses to assess relations between seasonal variation in POC composition and changes in the relative proportions of headwater-sourced and floodplain-sourced POC. We assume four possible POC endmembers: leaf litter, soil (i.e., organic-rich soil developed within the top 5 cm of the floodplain surface), aged floodplain sediment (deposits older than 100 years and from material >50 cm depth), and bedrock. Both leaf litter and soil can be sourced from the headwaters and floodplains, therefore, the presence of these endmembers is not diagnostic of either headwater-sourced or floodplain-sourced POC. In contrast, bedrock-derived POC_{petro} originates exclusively in the Río Bermejo headwaters (although POC_{petro} can be transiently stored in the Lowland

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Bermejo floodplain during source to sink transport), while aged floodplain sediment comes primarily from the Lowland Bermejo, allowing us to use these endmembers as proxies for the relative contributions of headwater and floodplain-sourced POC. To determine the contributions of endmembers to the POC in the suspended sediment samples, we used MixSIAR, an open-source Bayesian tracer mixing model framework (Stock et al., 2018) which provides a probabilistic solution to endmember mixing. MixSIAR assumes geochemical tracers (e.g., N/OC, $\delta^{13}C_{OC}$, and Fm) are conserved in the mixing process and that tracer composition is known and invariant. MixSIAR allows for correlation between tracers and integrates the observed variability in endmember and mixture composition (Moore & Semmens, 2008; Parnell et al., 2013; Stock et al., 2018), and has been used for fluvial POC (Blake et al., 2018; Menges et al., 2020). We parameterized MixSIAR using TOC-weighted means and standard deviations of N/OC, $\delta^{13}C_{OC}$, Fm for each endmember. We ran calculations for samples with measurements of N/OC, $\delta^{13}C_{OC}$, and Fm, and grouped suspended sediments into five discharge bins of >9 samples ($Q_w < 100$ m³/s, $100 < Q_w < 200$ m³/s, $200 < Q_w < 400$ m³/s, $400 < Q_w < 800$ m³/s, $Q_w > 800$ m³/s). We used an uninformative prior, ran each model with a chain length of 10^6 and tested its convergence with Gelman-Rubin (Gelman & Rubin, 1992) and Geweke Diagnostics (Geweke, 1991). Models reached convergence after runs with 3×10^5 iterations, a burn-in of 2×10^5, and 3 chains.

4. Results

4.1. Water Discharge, Sediment Mass and Channel Migration Rates

Water discharge varied from 45 to 1,300 m³/s over the study period and was positively correlated with suspended sediment sample mass (Figures 2a and 2b). We assessed grain size using the median grain diameter (D_{50}) and fraction of grains <2 µm (f_2, Scheingross et al., 2021). D_{50} and f_2 of surface water samples varied from 3 to 6 µm and 0.12 to 0.70, respectively, with no systematic seasonal trends (Table S1).

Channel migration rates increased from ∼13 to 15 m/yr in the dry season to ∼55 m/yr in the wet season, ∼10× faster than average migration rates for rivers with vegetated banks of similar width (Ielpi & Lapôtre, 2020). Erosion occurred predominately on the outer side of channel bends in the wet season; we observed no systematic relationship between channel curvature and dry season erosion (Figure S1). Migration rates were typically <30 m (near our detection limit using Sentinel-2 imagery, Supplementary Text) along the entire channel length in the dry season, and along portions of the channel during the wet season. Therefore, both migration rate estimates likely include mapping errors and overestimate the true migration.

4.2. Seasonal POC Variation

Suspended sediment TOC ranged from 0.32% to 0.92% (Figures 2c and 3a, Table S1). For the dry season ($Q_w < 400$ m³/s), TOC had a statistically significant negative correlation with discharge ($\rho = -0.64$, $p < 10^{-5}$) (Figure 3a). While in the wet season ($Q_w > 400$ m³/s), TOC averaged 0.35% ± 0.06%, showing no statistically significant correlation with discharge ($\rho = -0.30$, $p = 0.11$, Figure 3a). Temporal TOC changes were gradual, typically increasing from the middle of the wet season until the end of the dry season (Figure 2c). We also observed a statistically significant correlation between D_{50} and TOC ($p = 0.01$) and a suggestive correlation between f_2 and TOC ($p = 0.06$); however, there is no statistically significant correlation between either D_{50} or f_2 and water discharge (Figure S6), likely because we sampled only surface water, thereby limiting grain size variations.

Suspended sediment $\delta^{13}C_{OC}$ values ranged from −26.9‰ to −24.3‰ (Figures 2d and 3b, Table S1). For $Q_w < 400$ m³/s, $\delta^{13}C_{OC}$ showed a statistically significant linear correlation with discharge ($\rho = 0.71$, $p < 10^{-7}$, Figure 3b). For $Q_w > 400$ m³/s, $\delta^{13}C_{OC}$ varied between −26.1‰ and −24.6‰ with no statistically significant correlation with discharge ($\rho = -0.32$, $p = 0.08$, Figure 3b). Temporal variation in $\delta^{13}C_{OC}$ values were gradual, with occasional spikes (e.g., June 2017, Figure 2d).

Fm ranged from 0.66 to 0.83 (with one outlier, Fm = 0.56, Figures 2e and 3c, Table S1). During the dry season, Fm and Q_w showed a statistically significant positive linear correlation with discharge ($\rho = 0.80$, $p < 10^{-4}$, Figure 3c). In the wet season, Fm remained approximately constant, showing no significant correlation with discharge ($\rho = 0.02$, $p = 0.95$, Figure 3c). N/OC ratios varied between 0.2 and 0.44, with no significant correlation between N/OC and discharge (Figure 3d and Table S1) and did not show consistent temporal variations (Figure 2f).

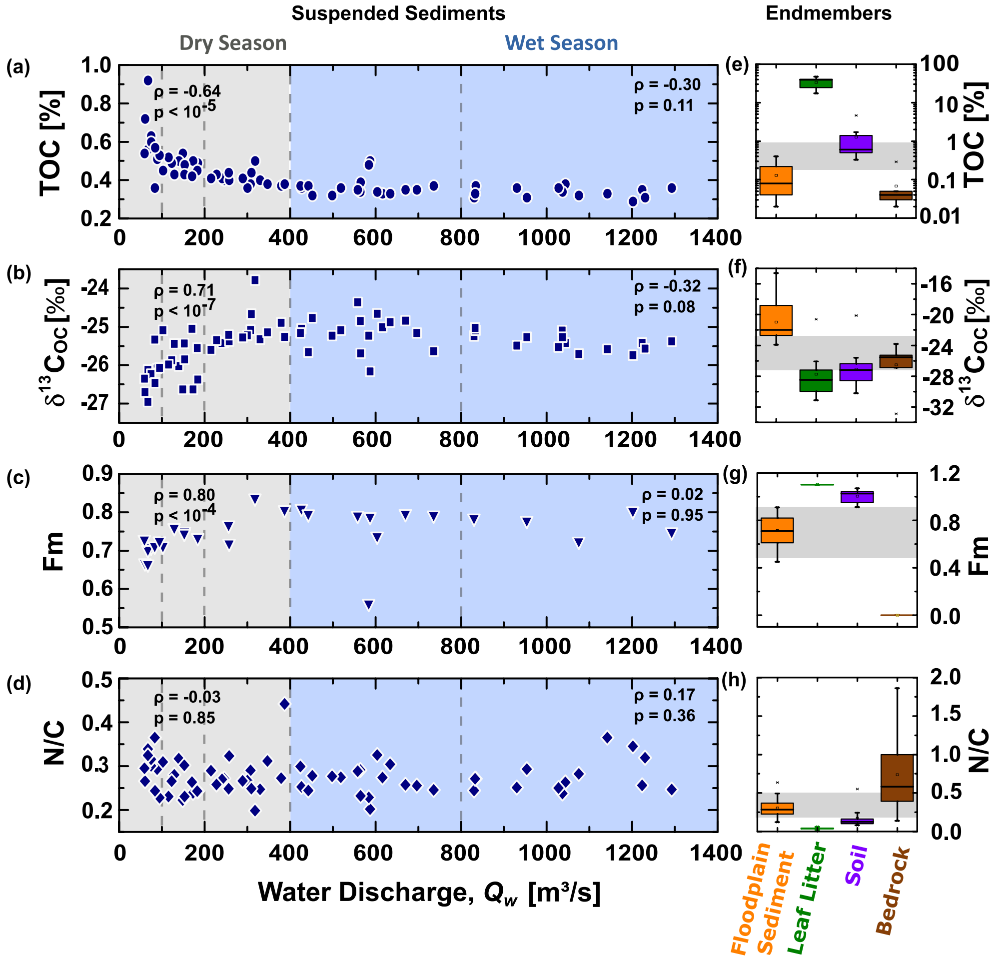

Figure 3. Variations in suspended sediment (a) total organic carbon (TOC), (b) $\delta^{13}C_{OC}$, (c) Fm, and (d) N/OC as a function of water discharge at Puente Lavalle (PLV). ρ and p are the Pearson correlation coefficient and significance level, respectively. Dashed lines represent discharge bins used in Figure 4. (e–h) Endmember boxplots; boxes show interquartile range and mean with whiskers corresponding to the 95th and 5th percentile of measured values. Gray shading shows (a–d) extent.

4.3. Endmember Contributions

Endmember POC sources showed partial overlap in measured values of TOC, $\delta^{13}C_{OC}$, Fm, and N/OC (Figures 3e–3h and S2). We set Fm = 1.1 for leaf litter and measurements displayed 0.02 < N/OC < 0.06 and −31‰ < $\delta^{13}C_{OC}$ < −21‰. Soil measurement ranged from 0.09 < N/OC < 0.55, −30‰ < $\delta^{13}C_{OC}$ < −20‰, and 0.9 < Fm < 1, while floodplain sediment showed 0.15 < N/OC < 0.5, −23‰ < $\delta^{13}C_{OC}$ < −14‰, and 0.5 < Fm < 0.9. Bedrock had 0.14 < N/OC < 2, −32.9‰ < $\delta^{13}C_{OC}$ < −23.8‰, and was set to Fm = 0 by definition (Tables S2 and S3). MixSIAR posterior distributions of endmember contributions to the total POC load were broader for leaf litter and soil than floodplain sediment and bedrock, reflecting the more similar isotopic composition of the former (Figure 4a and Table S2). The floodplain sediment contribution increases with discharge, reaching a maximum mean value of 44% at 400 < Q_w < 800 m³/s, while the contribution from bedrock decreases with discharge, reaching a minimum of 13% at 400 < Q_w < 800 m³/s. Posterior distributions of soil and leaf litter remain approximately constant with discharge (Figure 4a). These results agree with the mixing diagrams (Figure S2) which show that dry season samples (Q_w < 400 m³/s) generally have lower Fm and $\delta^{13}C_{OC}$ values than wet season samples (Q_w > 400 m³/s).

We estimated the contribution of individual endmembers to the overall OC flux by multiplying the mean value of its posterior distributions by the POC flux (Supplementary Text S3) for a given discharge bin (Figure 4b). The soil endmember dominates the POC flux throughout all discharges, while the floodplain endmember has high contributions in the wet seasons and is overtaken by the bedrock endmember in the dry seasons. We also compared

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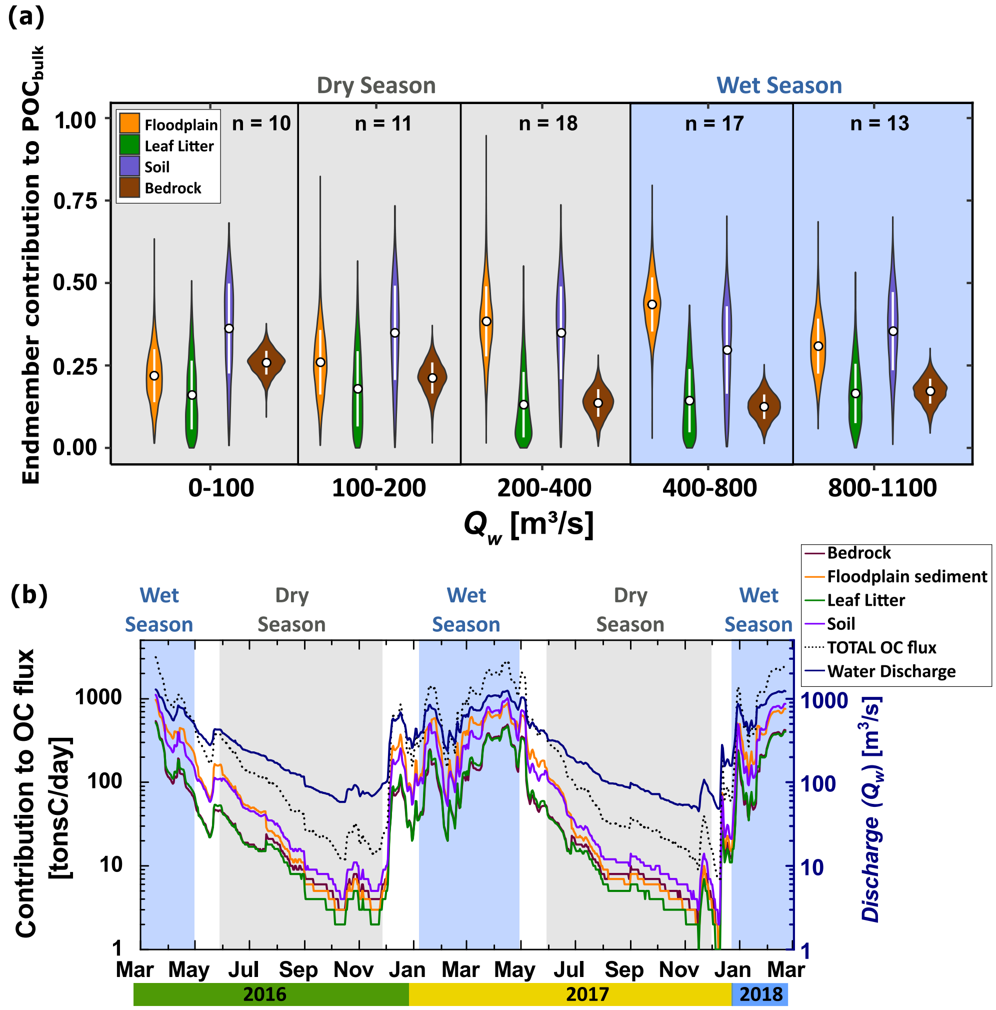

Figure 4. MixSIAR-derived contributions of soil, leaf litter, floodplain sediment, and bedrock endmembers to the bulk particulate organic carbon (POC) load. (a) Full posterior distributions; white dots and centerlines represent posterior mean and standard deviation, respectively; *n* denotes the number of samples per discharge bin. (b) Temporal variation in endmember contributions to the OC flux.

suspended sediment collected at the PLV monitoring station with samples previously collected ~900 km upstream at the mountain front (Scheingross et al., 2021), which provide an approximation of the bulk headwater POC composition. Mountain front samples and suspended sediment collected in the dry season at PLV overlap in $\delta^{13}C_{OC}$ and N/OC values, but mountain front samples have slightly higher Fm values than suspended sediment at PLV (Figure S2).

5. Discussion

5.1. Seasonal Variation of POC Source

Our results suggest that compositional changes in POC with increasing discharge reflect increasing proportions of floodplain-sourced POC relative to (headwater-sourced) POC_{petro} (Figures 4a and 4b). Our analysis of the MixSIAR results relies heavily on relative changes in the posterior distributions of POC_{petro} and aged floodplain sediment POC, because the relatively uniform C_3 vegetation throughout the catchment suggests that both headwater-sourced and floodplain-sourced leaf litter and soil are likely to have similar compositions. Our estimates of the headwater-derived OC flux is therefore likely a minimum estimate, as it does not include the headwater OC_{bio} component. The MixSIAR results indicate that POC samples depleted in ^{13}C in the dry season primarily reflect soil and bedrock contributions, with lesser contributions from floodplain sediment and leaf litter (Figures 4a

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and 4b). This implies that the Bermejo is most efficient in transporting headwater-sourced POC in the dry season, consistent with the agreement between $\delta^{13}C_{OC}$ and N/OC values of suspended sediment collected at the mountain front and dry season suspended sediment collected downstream at PLV (Figure S2). Headwater-sourced POC contributions likely increase in the dry season because low discharge limits channel bank erosion, thereby reducing the input of floodplain-sourced POC. The relative enrichment in ^{13}C and ^{14}C for POC from ∼100 to 800 m^3/s reflects an increase in floodplain sediment and decrease in POC_{petro} (Figure 3), and likely results from increased channel migration rates. For $Q_w > 800$ m^3/s, MixSIAR results show that the floodplain sediment POC contribution is slightly lower and bedrock POC contribution is slightly higher than those calculated for the 400–800 m^3/s bin (Figure 4a). This could reflect the lofting of POC_{petro}-enriched bed material to the water surface at very high discharges; however, floodplain-sourced POC still remains a larger contribution to the total POC load than at low discharges, consistent with our hypothesis that increased discharge increases the representation of floodplain-sourced POC in the fluvial load.

The seasonal variation in floodplain-sourced relative to headwater-sourced POC is consistent with our observations of seasonally variable river lateral migration. Lateral channel migration allows for sediment deposition in point bars and the erosion of floodplain sediment from cut banks, such that the rate of lateral migration and the distance downstream from the mountain front should set the relative fraction of floodplain-sourced versus headwater-sourced POC. We interpret discharge-induced changes in lateral migration rate are more likely to set POC composition than the potential for discharge-induced changes in grain size, as we observe no statistical correlation between water discharge and grain size in our samples (Figure S6). Repasch et al. (2020) used decadal-averaged river migration rates to estimate that, on average, the sediment load of the Bermejo exchanges completely with the floodplain every ∼280 km. This implies that most sediment reaching the PLV monitoring station, ∼870 km downstream of the mountain front, has experienced ∼3 cycles of floodplain deposition, transient storage, and re-erosion. We thus expect the vast majority of sediment passing the PLV station in the wet season (when lateral migration rates are high) to be floodplain-sourced, consistent with our geochemical observations. Conversely, in the dry season, limited sediment exchange between the channel and floodplain allows a greater fraction of headwater-sourced sediment to bypass PLV without floodplain storage. This implies that during low flows with negligible river-floodplain exchange, POC may travel from source to sink over days to weeks, whereas during high flow, exchange with the banks results in floodplain storage and transit times that can extend to millennia (Repasch et al., 2020).

5.2. Implications for POC Export to Depositional Basins

To explore how seasonal variability may affect POC composition delivered to basins, we estimated Río Bermejo POC export (Supplementary Text and Figure S5) using the 26-year daily water discharge record (*SNIH*), a Q_w-TOC rating curve (Figure S3) and a sediment flux versus water discharge rating curve (Figure S4). From dry to wet seasons there is a threefold decrease in POC concentration; however, the increase in sediment flux results in an ∼100-fold increase in POC flux. Integrating over the 26-year daily discharge record, we estimate that the aged floodplain sediment flux is ∼2.1 times greater than POC_{petro} flux, suggesting that floodplain-sourced POC dominates contributions to downstream sedimentary basins. We suggest that POC deposited in basins downstream of actively migrating rivers with large floodplains, such as the Río Bermejo, is likely to be sourced primarily from adjacent floodplains, and that the input of headwater material is likely to be overprinted before organic matter reaches its final sink. As sediment and POC can take order 10^3 yr to transit lowland rivers (Repasch et al., 2020; Wittmann et al., 2015), these results imply that paleoclimate information recorded in POC deposited downstream of lowland rivers is likely not sensitive to high frequency ($<10^3$ yr) climatic variations. Instead, high frequency climate signals and headwater-sourced POC may be better preserved in deposits of small mountain streams draining directly to the ocean.

6. Conclusions

Our data suggests that low channel migration rates cause the Río Bermejo to act as a conduit preferentially transporting headwater-sourced POC in the dry season, while in the wet season, high lateral channel migration rates drive significant influxes of floodplain POC into the river load that overprint the headwater signature. The wet season comprises ∼85% of the total annual POC flux, suggesting that the majority of organic matter exported from the Bermejo derives from the lowlands. This work highlights how hydrologic variability sets the

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composition of POC exported from lowland rivers, allowing improved interpretation of the provenance of organic material preserved in depositional centers.

Data Availability Statement

All data are accessible though the PANGAEA data repository (https://doi.org/10.1594/PANGAEA.932558), in Scheingross et al. (2021) and available for download from *SNIH* (Sistema Nacional de Información Hídrica, https://snih.hidricosargentina.gob.ar/).

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