EFFECTS OF SUSPENDED SEDIMENT TRANSPORT ON INVERTEBRATE DRIFT IN A PIEDMONT RIVER CHANNEL: THE UPPER RIVER CINCA (SOUTH CENTRAL PYRENEES)

MARÍA BÉJAR
Fluvial Dynamics Research Group, University of Lleida, E25198 Lleida, Spain

DAMIÀ VERICAT
Fluvial Dynamics Research Group, University of Lleida, E25198 Lleida, Spain
Forest Technology Centre of Catalonia, Solsona, E25280 Lleida, Spain

CHRIS GIBBINS
Northern Rivers Institute, University of Aberdeen, Old Aberdeen, AB24 3UF, United Kingdom

RAMON J. BATALLA
Fluvial Dynamics Research Group, University of Lleida, E25198 Lleida, Spain
Catalan Institute for Water Research E17003, Girona, Spain

In this paper we examine how changes in suspended sediment transport influence invertebrate drift in a piedmont river (the Upper Cinca, South Central Pyrenees). In-channel gravel mining in the Cinca causes the release of large amounts of fine sediment from the river bed, resulting in high suspended sediment concentrations (SSC) downstream. This in-channel gravel mining provided the occasion to assess the influence of increased SSCs on invertebrate drift during periods of constant flow hydraulics. Water and drift sampling was undertaken on six days (two events concurrent with river bed mining and four events pre and post mining activity periods), at five sampling sections distributed along a 5-km reach (one site upstream of the impacted area and four downstream). The magnitude of the SSC increment associated with mining was similar to that observed in natural floods. Drift was highly variable, reflecting natural spatio-temporal heterogeneity. However, mean drift rates increased appreciably during mining and showed a significant positive relationship with SSC. Ongoing work will assess changes in the river's morphosedimentary dynamics resulting from mining activity, and the implication of these changes for benthic assemblages.

1 INTRODUCTION

River channel disturbance is considered a key factor affecting benthic invertebrate community structure [1]. During disturbances (i.e. floods, instream mining), losses from the benthos occur as a result of involuntary invertebrate drift. This involuntary drift, along with so-called voluntary or behavioural drift, plays an important role in the dispersal and population dynamics of invertebrates in rivers worldwide [2]. Understanding how channel disturbance affects drift is therefore of great scientific and applied interest. In-channel gravel mining causes major bed disturbance, with consequences for channel morphology and sediment transport dynamics, at different temporal and spatial scales. Unlike natural channel disturbances associated with seasonal floods, those caused by in-channel gravel mining result in high suspended sediment concentrations (SSC), without any changes to flow hydraulics. Within this context, research described in this paper assessed changes in SSC and invertebrate drift associated with in-channel gravel mining in a piedmont river located in the Southern Pyrenees.

2 STUDY AREA AND METHODS

The 5-km long study reach is located in the upper River Cinca (Ebro Basin; Figure 1A). The Cinca is characterized by frequent competent flood events. Mean annual flow (1959-2015) is 29 m^3/s and annual floods exceed 223 m^3/s, while flows of 587 and 740 m^3/s have a recurrence of 5 and 10 years, respectively. River bed sediments are very poorly sorted; the range of surface particle sizes encompasses large boulders to patches of fine gravels and sands (i.e. from 0.5 to 2000 mm). The mean SSC for the study period (2013-2015) was 0.09 g/l (turbidity data registered in a monitoring station near DS4 in Figure 1A). Maximum instantaneous SSC at this station was 17.4 g/l, which was the same as observed during a flood event registered in summer 2015. The Upper Cinca has a long history of in-channel gravel mining. Historically, some sections of the river have been riprapped, decreasing the width of the floodplain. Additionally, substantial land-use changes in the headwaters have taken place in the last century, notably land abandonment and the subsequent natural afforestation. All these impacts have resulted in changes in the river, which is slowly shifting from a braided to a wandering platform, gravel bars have been vegetated and stabilized, and the river channel is now incised.

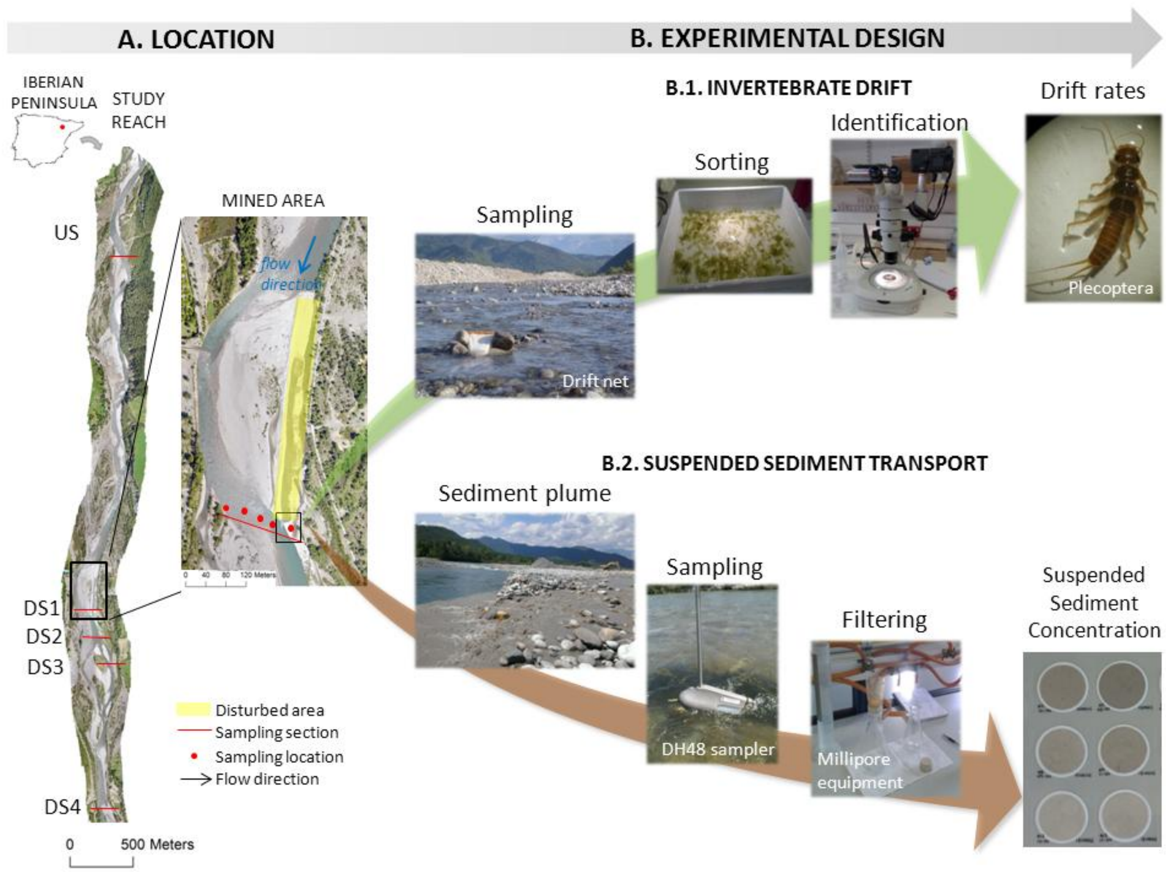

Figure 1. (A) Location of the Upper River Cinca and the 5-km study reach. Gravel mining took place in August 2014 in the section highlighted in yellow. (B) Schematic representation of the workflow used to generate drift and suspended sediment data.

Fieldwork was carried out in August 2014. During this month, excavators periodically entered the channel to remove gravel during two out of six sampling days (mined area; Figure 1A). SSCs and macroinvertebrate drift were sampled at sites upstream and downstream of the mined section (US, DS1-DS4; Figure 1A).

Invertebrate drift was sampled in riffles using standard drift nets (40×20 cm frame and a mesh of 1000 μm). Nets were left in place for a long enough period to collect sufficient animals for robust statistical analysis; sample time ranged from 240 to 420 minutes. On each day, five drift samples (positioned laterally across the full width of the channel) were collected in each of five sections (Figure 1A-B). The first section (US) was located 3500 m upstream from the mining, with the remaining sections located at 5, 200, 400 and 1500 m downstream. This design allowed assessment of the magnitude of changes in drift to increases in SSC, and evaluation of the downstream extent of drift changes.

Drift samples were preserved in alcohol until being processed in the laboratory, where they were sorted and identified to genus level (Figure 1B). Identification was based on Tachet et al. [3]. Water samples were collected in each section on each drift sampling occasion using a USDH48 Depth-Integrating sampler and an automatic water sampler (ISCO® 3700). Water samples were filtered, dried and weighed in order to determine SSC (in g/l; Figure 1B). Relations between SSC and drift rates were assessed using Generalised Estimating Equations (GEEs). GEEs are linear models that allow analysis of data that may not be truly independent because of serial correlation (e.g. repeat measurements at the same locations) or because samples are clustered (e.g. grouped within sites). GEEs were appropriate to our data because drift was repeatedly sampled at the same points across the same sections and because individual samples were geographically clustered by site/section. GEEs were applied to log transformed drift data. Goodness of fit was assessed using Quasi-likelihood values, with significance determined for Wald Chi^2 values for the intercept and slope of the fit of drift rate to SSC.

3 RESULTS AND DISCUSSION

3.1. Suspended sediment transport

In total, 135 water samples were obtained during the sampling days. SSC data is summarised in Figure 2A. Flow was low, at 7.5 m^3/s (coefficient of variation ±60%), this is a very frequent flow for a piedmont river like this and it is equalled or exceeded 25% of the time.

SSCs in the section upstream of the mining ranged from 0.0002 to 0.05 g/l; the mean was 0.018 (SD = 0.017 g/l). Downstream from the mining activity (sections DS1 to DS4) on the days when mining was not taking place, SSC ranged from 0.009 to 0.07g/l; the mean was 0.007(SD= 0.0123 g/l). During mining, mean SSC was one order of magnitude higher than this (i.e. 0.19 g/l), while the maximum instantaneous concentration reached 5.8 g/l. Maximum values were recorded in the sections closest to the mining (i.e. DS1, the section highlighted in Figure 1A and shown in the photograph in 1B). Concentrations recorded during mining were similar to those recorded during natural floods. For instance, mean SSC during a flood in June 2015 was 0.88 g/l, while the maximum was 7.46 g/l.

3.2. Invertebrate drift and drift responses to increases in fine sediment transport

Patterns in the 150 drift samples collected during the study period are summarised in Figure 2B. Across all these samples, drift rate ranged from 5.3 to 150 individuals/m^2/hour. The most abundant taxa in the drift were *Baetis*, *Ephemerella* and Orthocladinae, together accounting for 67% of all individuals recorded.

Upstream from the mining site (US section), drift rate ranged from 13 and 150 individuals/m^2/hour; the latter was the highest rate recorded at any of the sites during the study period. Average drift rate in the downstream sections during periods without mining was 44 individuals/m^2/hour (SD= 21 individuals/m^2/hour), while during mining this increased to 77 individuals/m^2/hour (SD= 35 individuals/m^2/hour). Maximum rate in these sections was 145 individuals/m^2/hour, obtained during a period of mining when SSC was high (DS2, 200 m downstream from the mined area; SSC = 0.14 g/l).

GEEs indicated a significant positive relationship between SSC and drift rate (Goodness of fit 69; Wald Chi^2 38.50, $P<0.001$). Thus, increases in SSC were paralleled by increases in drift rate. The intercept of the model fit using GEEs was significantly greater than zero (Wald Chi^2 63871, $P<0.001$); thus, drift can be expected in the Cinca in the absence of (detectable) suspended sediment transport. The spread of the drift values across the SSC gradient provides some potentially useful insights into the dynamics of drift. There was marked variability in drift at low SSC values, indicating that other factors are dictating variation in drift rates when suspended sediment is low or minimal. Such factors may include local differences in benthic densities, and hence the pool of available drifters, or invertebrate behaviour. At higher SSCs, drift was not only generally higher (as indicated by the GEE model output) but was less variable. The slopes of the upper and lower bounds of the drift scatter indicate that minimum drift expected for any given value of SSC increases at a faster rate than the maximum.

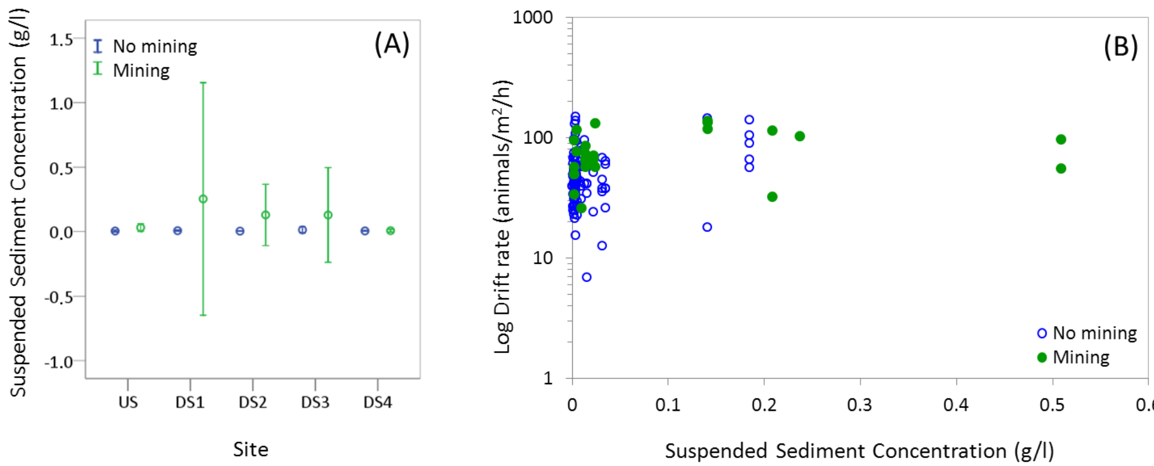

Figure 2. (A) Average suspended sediment concentrations recorded at the sections during August 2014. Error bars indicate one standard deviation above and below the average; (B). Invertebrate drift response to changes in suspended sediment.

4. CONCLUDING REMARKS

Results presented here are part of multidisciplinary research designed to assess the impacts of gravel mining on channel morphodynamics and macroinvertebrate communities. Data on bed grain size characteristics, hydraulic conditions, topography, bedload and suspended sediment transport, as well as benthic and drifting invertebrates are all being collected using a BACI [4] experimental design. Preliminary data presented here indicate that gravel mining results in marked increases in SSC, reaching values similar to those observed during natural flood events. Invertebrates apparently respond to these increases by leaving the bed and drifting downstream. Further comprehensive analysis of the full data set will allow us to more fully understand the physical and ecological disturbance effects of gravel mining and the conditions experienced by animals during mining.

ACKNOWLEDGMENTS

This research is funded by the Spanish Ministry of Economy and Competiveness and the European Regional Development Fund Scheme (CGL2012-36394; see more details of the project in www.morphsed.es). The first author has a PhD grant funded by the University of Lleida. The second author is founded by a Ramon y Cajal Fellowship (RYC-2010-06264). Authors acknowledge the support from the Economy and Knowledge Department of the Catalan Government through the Consolidated Research Group: 2014 SGR 645 (RIUS- Fluvial Dynamics Research Group). Hydrological data were supplied by the Ebro Water Authority (CHE). We thank CHE and Acciona for their logistic support. We also thank all help provided by the members of the Fluvial Dynamics Research Group.

REFERENCES

[1] Gibbins C., Vericat D. and Batalla R. J., *"When is stream invertebrate drift catastrophic? The role of hydraulics and sediment transport in initiating drift during flood events", Freshwater Biology*, Vol. 52, (2007), pp 2369–2384

[2] Waters T.F. *"The drift of stream insects", Annual Review of Entomology*, Vol. 17, (1972), pp 253–272.

[3] Tachet H., Richoux P., Bournaud M. and Usseglio-Polaterra P., *"Invertebres d'Eau Douce".* CNRS Editions, (2002).

[4] Underwood A.J., *"Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world", Journal of Experimental Marine Biology and Ecology*, Vol. 161, (1992), pp 145-178.