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Sediment tracing in the upper Hunter catchment using elemental and mineralogical compositions: Implications for catchment-scale suspended sediment (dis)connectivity and management

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ABSTRACT

River bed colmation layers clog the interstices of gravel-bed rivers, impeding the vertical exchange of water and nutrients that drives ecosystem function in the hyporheic zone. In catchments where fine-grained sediment supply has increased since human disturbance, understanding sediment provenance and the (dis)connectivity of supply allows practitioners to target sediment source problems and treat them within catchment management plans.

Release of alluvial fine-grained sediment from channel bank erosion since European settlement has resulted in the formation of a colmation layer along the upper Hunter River at Muswellbrook, eastern Australia. X-ray fluorescence spectrometry (XRF) and X-ray diffractometry (XRD) are used to determine the elemental and mineralogical signatures of colmation layer and floodplain sediment sources across this 4480 km^2 catchment. This sediment tracing technique is used to construct a picture of how suspended sediment supply and (dis) connectivity operates in this catchment. In this system, the primary source areas are subcatchments in which sediments are stored largely in partly confined floodplain pockets, but from which sediment supply is unimpeded and directly connected to the receiving reach. Subcatchments in which alluvial sediment storage is significant — and which contain large, laterally unconfined valleys — are essentially 'switched off' or disconnected from the receiving reach. This is because large sediment sinks act to trap fine-grained sediment before it reaches the receiving reach, forming a buffer along the sediment conveyor belt. Given the age structure of floodplains in the receiving reach, this pattern of source area contributions and (dis)connectivity must have occurred throughout the Holocene.

1. Introduction

Longitudinal, lateral, and vertical spatial linkages occur in catchments; and hydrological and sedimentological (dis)connectivities in these dimensions drive ecosystem-scale processes and patterns (Ward, 1989; Ward et al., 2001; Kondolf et al., 2006; Fryirs et al., 2007a,b). Principles such as the River Continuum Concept, Serial Discontinuity Concept, Nutrient Spiralling Model, and Hyporheic Corridor Concept view ecological (dis)connectivity and biotic response as functions of physical stream structure and sediment flux at different spatial and temporal scales (Ward and Stanford, 1983; Poole, 2002; Poole et al., 2008; Poole, 2010). While longitudinal and lateral fluxes of water, sediment and nutrients have received significant attention, the functioning of vertical linkages is less well understood (Boulton, 2007; Poole et al., 2008).

The hyporheic zone occurs below the channel bed and banks of river channels. In this zone, surface water and groundwater exchanges occur (Boulton et al., 1997). This exchange drives the biogeochemical transformation of water, mediated by active microbial biofilms (Boulton, 2007). A range of invertebrates that graze biofilms also inhabits this zone, contributing to secondary production (Boulton, 2007). This exchange is most effective in gravel-bed rivers where relatively rapid subsurface flow pathways occur in the interstices between clasts. The retentive capacity of the hyporheic zone and its ability to perform functions such as nutrient cycling and organic matter processing are controlled by the geomorphic structure of the channel bed, amongst other things (Poole, 2002, 2010). Therefore the physical structure, heterogeneity, and sedimentology of the channel bed is a key control on the effectiveness of hyporheic zone functioning. Damaging vertical linkages can significantly impact on river ecosystem function, and the rehabilitation of these linkages should receive greater attention in holistic management plans (Boulton, 2000; Ward et al., 2001). One such example occurs along the upper Hunter River at Muswellbrook where suspended sediments have formed colmation layers, where fine-grained sediment blankets or clogs the interstices between clasts significantly impairing the hyporheic functioning of this river system (Mika et al., 2010).

Human activities can disrupt vertical exchange mechanisms between surface water and groundwater. Alterations to water quality

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and quantity and changes to the biota that inhabit the hyporheic zone are common (see reviews in Brunke and Gonser, 1997; Boulton, 2000; Boulton et al., 2003). Often underpinning these disturbances are physical changes to river structure and function (Brierley and Fryirs, 2008). *Direct* physical disturbance commonly involves disruption of surface armour on gravel bars or extraction/mining of gravel from the bars and bed (Kondolf, 1994, 1997). *Indirect* physical disturbance commonly involves the influx of sediment from upstream sources, resulting in two types of outcome. Firstly, in transport-limited systems, oversupply of bedload sediment and the formation of sediment slugs can smother the channel bed, reducing its heterogeneity and removing the topographic variability required to produce pressure heads that drive downwelling into, and upwelling out of, the hyporheic zone. Secondly, in systems where suspended sediment supply is high (or has increased after catchment disturbance) interstitial sedimentation or clogging of the hyporheic zone occurs, significantly reducing the porosity of the gravel bed and inhibiting the exchange of water between the surface and subsurface. In the latter case, colmation layers are formed on, or within, the gravel bars and channel bed (Boulton et al., 2003).

Colmation layer(s) can form via a number of mechanisms associated with suspended sediment transport along river channels (Frostick et al., 1984; Lisle, 1989; Droppo and Stone, 1994). During the waning stages of floods or in stillwater areas of river channels, fine-grained sediment settles out of suspension, blanketing gravel bars and the channel bed (Fig. 1). As these sediments settle, they fill the interstices of gravel bars, clogging the spaces between larger gravel clasts. These fine sediments may eventually move through the profile of the gravel bar resulting in the formation of a colmation layer within the bar itself. Alternatively, additional sheets of gravel may be deposited atop the gravel bar, burying the mud drape and the previous gravel surface (Fig. 1). To treat the causes of fine-grained sedimentation and colmation layer formation requires that the dominant source areas in a catchment and their (dis)connectivity to receiving reaches be known (Collins and Walling, 2007; Fryirs, 2013). Informed decisions can then be made to prioritise and treat sediment sources as part of catchment action plans.

Sediment fingerprinting links the mineralogical or geochemical properties of the sediment (in this case the colmation layer) and its source material. If source materials can be distinguished by their geochemical properties, the likely source of the sediment can be established by comparing the properties of the sediment with source materials (Walling et al., 2003). The need to discriminate several potential sediment source areas means that a single fingerprint property is generally unlikely to provide a reliable source fingerprint. Therefore, most recent source fingerprinting studies have used composite fingerprints, comprising a range of different diagnostic properties and mixing models to quantify the relative contributions of sediment from different sources (Walling et al., 1993; Walling and Woodward, 1995; Collins et al., 1997, 1998, 2001; Collins and Walling, 2002; Walling et al., 2003; Collins and Walling, 2007; Weltje, 2012). The predicted lack of discrimination between subcatchments at a useful spatial scale, precluded the use of quantitative apportionment in this study. Instead, the aims are to firstly establish the provenance of fine-grained sediment trapped in the colmation layer of the upper Hunter River at Muswellbrook using X-ray fluorescence spectrometry (XRF) and X-ray diffractometry (XRD) with a view to improving understanding of fine-grained sediment dynamics in this catchment. Secondly, we aim to provide the information required to prioritise suspended sediment source areas for consideration in catchment action and rehabilitation plans.

2. Regional setting and geomorphic river changes in the upper Hunter catchment

The Hunter catchment drains an area of 22,000 km^2. The upper Hunter catchment covers an area of 4480 km^2 upstream of Muswellbrook and is located in the north eastern inland region of the catchment (Fig. 2). The north–south oriented Hunter–Mooki Fault separates the catchment into two geological provenances. The fault defines the boundary between Sydney basin and the New England fold belt strata. The eastern side generally comprises Carboniferous and Devonian metasediments, with a Tertiary basalt cap at high elevations.

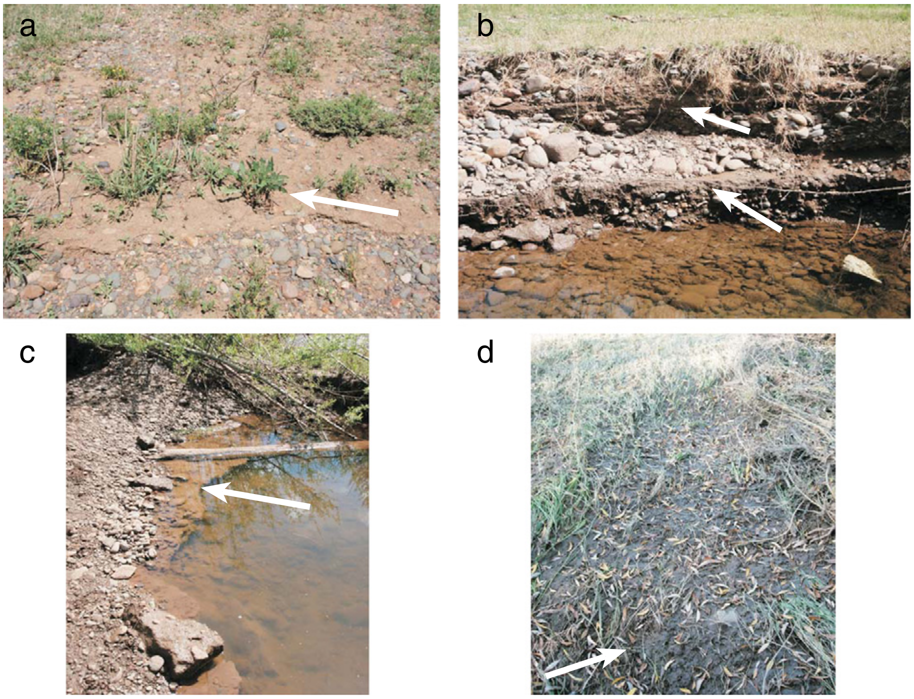

Fig. 1. Photographs showing various forms of colmation layers along the upper Hunter River at Muswellbrook. Arrows point to fine-grained deposits. (a) Embedded bar surface where fine-grained sediments clog the interstices of gravels, (b, c) Colmation layers within the stratigraphy of bars, (d) 2007 flood deposit/blanket on a gravel bar. Photographs: K. Fryirs.