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Temporal effects of enhanced fine sediment loading on macroinvertebrate community structure and functional traits

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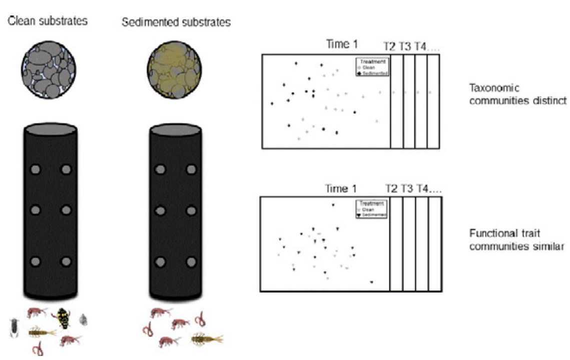
HIGHLIGHTS

- Fine sediment effects on macroinvertebrate traits and assemblages were examined.
- Analysis of taxonomic community structure identified strong fine sediment effects.
- Effects of sediment loading on community structure were not temporally consistent.
- Faunal traits performed poorly in characterising fine sediment effects.
- Taxon life cycles probably influence the effect of fine sediment load.

GRAPHICAL ABSTRACT



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ABSTRACT

Deposition of fine sediment that fills interstitial spaces in streambed substrates is widely acknowledged to have significant negative effects on macroinvertebrate communities, but the temporal consistency of clogging effects is less well known. In this study the effects of experimentally enhanced fine sediment content on aquatic invertebrates were examined over 126 days in two lowland UK streams. Taxonomic approaches indicated significant differences in macroinvertebrate community structure associated with sediment treatment (clean or sedimented substrates), although the effects were variable on some occasions. The degree of separation between clean and sedimented communities was strong within seven of the nine sampling periods with significant differences in community composition being evident. EPT taxa and taxon characterised as sensitive to fine sediment demonstrated strong responses to enhanced fine sediment loading. Faunal traits also detected the effects of enhanced fine sediment loading but the results were not as consistent or marked. More widely, the study highlights the temporal dynamics of sedimentation effects upon macroinvertebrate communities and the need to consider faunal life histories when examining the effects of fine sediment loading pressures on lotic ecosystems.

1. Introduction

Increased instream fine sediment loading is widely regarded as a global threat to ecological integrity and lotic ecosystem health, often leading to reduced macroinvertebrate diversity through direct exclusion of taxa, enhanced drift or reductions in the availability of suitable trophic resources and habitat (Larsen and Ormerod, 2010a; Jones et

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al., 2012; Wood et al., 2016). The infiltration of fine sediment into the river (colmation/clogging) has been reported to modify benthic macroinvertebrate community structure and functioning (Descloux et al., 2013). Substrates characterised by a high proportion of fine sediment are frequently dominated by taxa with low dissolved oxygen requirements (Angradi, 1999; Zweig and Rabeni, 2001) and exhibit an absence of taxa vulnerable to fine sediment due to impairment or damage of filter-feeding apparatus or delicate gills (Wood and Armitage, 1997; Larson et al., 2009). In addition, some taxa may be excluded and unable to colonise habitats where excessive fine sediment is present, for example due to the absence of suitable materials for case building by caddisfly larvae (Higler, 1975; Urbanič et al., 2005). Some functional feeding groups may also be disadvantaged by enhanced fine sediment loading, associated with reduced food quality or impaired access to food resources, notably for algal scrapers and filter feeders (Rabeni et al., 2005; Kreutzweiser et al., 2005). This may lead to shifts in community structure towards those dominated by deposit feeders (Relyea et al., 2012).

Some fauna respond to fine sediment deposition pressures as a function of their morphological characteristics and functional traits (Lamouroux et al., 2004; Bona et al., 2016; Doretto et al., 2017). Recently there has been a growing focus on the incorporation of faunal traits within biomonitoring tools to elucidate on the changes that occur to invertebrate community structure in freshwater ecosystems (Menezes et al., 2010; Göthe et al., 2016; Pilière et al., 2016). Biological traits are based on the habitat model concept (Southwood, 1977), and therefore community traits may reflect spatial and temporal variations in environmental factors (Townsend and Hildrew, 1994). Trait composition can also be used to identify sources of environmental impairment associated with anthropogenic and natural stressors which act as 'filters', selecting taxa with relevant adaptive traits. Consequently, some traits may be particularly sensitive to environmental pressures and it is this possibility that has led to the increasing application of biological traits within biomonitoring tools (Statzner et al., 2004; Friberg, 2014; Turley et al., 2016). However, relatively little information exists regarding how macroinvertebrate faunal traits respond to instream fine sediment loading and the limited studies in this area to date have yielded variable results (e.g. Buendia et al., 2013; Descloux et al., 2014).

The majority of studies conducted on sedimentation to date have focussed on artificial enhanced fine sediment loads (Suren and Jowett, 2001; Larsen et al., 2011) or have been associated with heavily sedimented river beds (Matthaei et al., 2010; Wagenhoff et al., 2012). A small number of studies have experimentally manipulated the volume of fine sediment within the substrate directly through the application of faunal colonisation devices, but these studies have typically examined the effects at a single point in time (Bo et al., 2007; Larsen et al., 2011; Pacioglu et al., 2012; Descloux et al., 2013, 2014). There is an absence of research that considers the temporal variability of fine sediment effects on macroinvertebrate communities and the value of life history traits for understanding and monitoring these effects.

Species phenology within a community affects the composition of macroinvertebrates observed at differing times of the year (Delucchi and Peckarsky, 1989; Murphy and Giller, 2000), and may confound biomonitoring assessments if not acknowledged (Clarke, 2013; Carlson et al., 2013). Temporal and spatial heterogeneity of hydrological regimes is also a fundamental process in shaping riverine macroinvertebrate communities (Dewson et al., 2007; Monk et al., 2008). Natural streams are typically characterised by stable baseflow conditions punctuated periodically by flow disturbances. These flow disturbances have important implications for fine sediment dynamics, initiating entrainment of fine material stored in the channel and increasing suspended sediment concentrations (Leopold et al., 1964; Bond and Downes, 2003). The interaction between flow and fine sediment dynamics (entrainment, suspension and depositional processes) has been identified as a primary factor which influences the turnover of taxa within macroinvertebrate communities (Rempel et al., 2000; Buendia et al., 2014; Jones et al., 2015). Consequently, as a result of temporal variability in flow and species assemblages, it follows that it is important to consider the effects of sediment loading over time.

This study is the first to specifically consider the temporal variability of experimentally manipulated fine sediment loading on macroinvertebrate communities at a fine temporal resolution (weeks). The following research questions were addressed:

(i) Is the effect of increased fine sediment loading on macroinvertebrate communities consistent temporally?
(ii) Which taxa and functional traits are associated with enhanced fine sediment loading?
(iii) Are the observed effects of enhanced fine sediment loading on macroinvertebrate communities evident and consistent for both taxonomic and faunal trait compositions?

2. Materials and methods

2.1. Field sites

The study took place on two small lowland rivers in Rutland, UK; the River Gwash (52°38′ N, 00°44′ W) and the River Chater (52°37′ N, 00° 44′ W). Sites were selected to be as broadly comparable in physical characteristics (channel size, water chemistry, altitude and geology) as possible. Both river channels were characterised by a riffle – pool morphology (channel width 2.9–6.5 m). Catchment geology was dominated by Jurassic mudstones and sandstones (British Geological Survey, 2008) and study sites were located in arable farmland. Close to the catchment outlets, mean daily flows were 0.18 $m^3 s^{-1}$ and 0.52 $m^3 s^{-1}$ for the River Gwash and Chater respectively (record 1978–2015; NRFA, 2017). Subsurface bed material (based on four pooled individual McNeil samples from two riffles per site, average sample weight 20.01 kg [McNeil and Ahnell, 1964]) indicated similar grain size distributions (GSD) between sites; with both being naturally characterised by a moderate fine sediment content (mass <2 mm; Gwash 20% and Chater 28.8%). Hydrological data from local gauging stations indicated that the study coincided with periods of stable flow punctuated by increased river stage associated with summer rainfall events (Fig. 1).

2.2. Colonisation columns

Macroinvertebrate colonisation columns were installed at the two sample sites. These comprised PVC cylinders (diameter 65 mm, height 200 mm) perforated with twelve horizontal holes (diameter 6 mm) to permit horizontal and vertical exchange of water and the free movement of macroinvertebrates and fine sediment (Fraser et al., 1996; Pacioglu et al., 2012; Descloux et al., 2013; Mathers and Wood, 2016). All columns were filled with a pre-washed gravel framework collected from each of the respective sample sites (truncated at 8 mm). This substrate was enclosed in a net bag (7 mm aperture) within each column. Columns were assigned to one of two treatments; a) clean substrates which were free from fines upon installation or; b) heavily sedimented substrates comprising gravel and 250 g of fine sand (63–2000 μm). Preliminary tests indicated that this volume of sand filled 100% of interstitial volume. For the sedimented columns, a circular disk (64 mm diameter) was attached to the mesh bag to effectively seal the base of the column and reduce the loss of fine sediment vertically into the riverbed.

Columns were inserted into the river bed by placing the PVC cylinders onto a steel pipe (35 mm diameter) that was driven into the river bed sediments until a sufficient depth was obtained to insert it flush with the substrate surface (200 mm). The surrounding stream bed remained unchanged and consisted of non-uniform cobbles and gravel. Columns were left in-situ for the entire sampling campaign, but every 14 days the gravel netting bag was removed and replaced without disturbing the surrounding gravel framework. At the end of