The impact of fine sediment accumulation on benthic macroinvertebrates: implications for river management

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Abstract

Fine sediment accumulation (particle size: <4mm) is a major cause of degradation to instream habitats and ecological condition in many Australian rivers. Benthic macroinvertebrates are commonly used indicators of river ecological condition that can be adversely affected by fine sediment accumulation. Sedimentation can change the suitability of the substrate for some taxa, increase macroinvertebrate drift and affect respiration and feeding activities. Only a few studies have focussed on the responses of individual taxa to sedimentation and many have not disentangled its impact from other associated land-use impacts. This paper describes current understanding of the ways in which fine sediment accumulation affects benthic macroinvertebrates. The paper then outlines the research needed to provide methods for assessing how fine sediment accumulation affects benthic macroinvertebrates at a regional scale. Such research is important for ongoing efforts to maintain and improve river health.

Keywords

Erosion, fine sediment, spatial scale, rehabilitation

Introduction

Sedimentation is widely acknowledged as a major cause of degradation to the ecological condition of rivers (e.g. Cordone & Kelley, 1961; Hogg & Norris, 1991; Hynes, 1970; Wood & Armitage, 1997). In Australia extensive fine sediment accumulation (particle size: <4mm) in stream reaches with low stream power (Bartley & Rutherfurd, 2005; Prosser et al., 2001b) has been triggered by upstream channel erosion (Rutherfurd, 2000). Fine sediment that smothers the river bed can kill aquatic flora, clog the interstitial spaces between larger substrate particles, reducing the available habitat for benthic organisms and increasing invertebrate drift (Doeg & Koehn, 1994; Waters, 1995; Wood & Armitage, 1997).

Benthic macroinvertebrates are widely used as indicators of ecological condition, because of their variety of responses to human disturbances, such as sedimentation (Rosenberg & Resh, 1993). They also have an important role in food webs and are a major food source for many species of freshwater fish (Waters, 1995). Government funding allocations for managing intact river ecosystems and rehabilitating those with recovery potential are commonly made at regional scales (1000-1,000,000 km²). However, historically there has been a paucity of data on river condition to inform these decisions (Lake 2005; Rutherfurd, 2000; Prosser et al., 2001b). This paper reviews the impact of fine sediment accumulation on macroinvertebrates that may be used to aid river and catchment managers. The paper then outlines the research needed to provide methods for assessing how fine sediment accumulation affects benthic macroinvertebrates at a regional scale. It only focuses on streambed accumulation, because it has a long-term ecological impact (Campbell & Doeg, 1989).

Fine sediment accumulation and macroinvertebrates

High levels of fine sediment input to rivers can significantly alter macroinvertebrate assemblages. Wood and Armitage (1997) identified four ways in which fine sediment can affect macroinvertebrates: (1) by altering substrate composition and changing the suitability of the substrate for some taxa (Hynes, 1970; Waters, 1995); (2) by increasing drift as a result of sediment deposition or substrate instability (Culp et al., 1986; Rosenberg & Wiens, 1978); (3) deposition on respiration structures affecting oxygen uptake or low oxygen
concentrations associated with fine sediment deposits (Waters, 1995); and (4) by affecting feeding activities by reducing the food value of periphyton (Graham, 1990) and reducing the density of prey items (Peckarsky, 1984).

There is a generally held view that an increase in fine sediment accumulation leads to changes in macroinvertebrate community composition, by favouring some macroinvertebrates at the expense of others (Hynes, 1970; Waters, 1995; Wood & Armitage, 1997). Many macroinvertebrate taxa belonging to the Ephemeroptera, Plecoptera and Trichoptera (EPT) orders, which provide the most productive and available food for stream fishes, are particularly affected by sedimentation. This is because sedimentation inhibits periphyton as food, density of prey items, available oxygen for respiration and interstitial space for refuge, which are necessary for the existence for many of these taxa, are inhibited by increased sedimentation (Waters, 1995). A study by Kaller and Hartman (2004) in seven Appalachian streams with different levels of sediment accumulation found consistent negative relationships with the finest substrate particles (<0.25mm) that exceeded 0.8-0.9% of riffle substrate composition and EPT taxa richness. In contrast, taxa such as Chironomidae, Oligochaeta and Sphaeridae are frequently associated with fine sediment, because they are able to burrow into the sediment (Waters, 1995). Therefore, when the streambed is degraded by fine sediment, there will be a point where macroinvertebrate communities become less diverse and numerically dominated by fine sediment tolerant taxa.

There have been few studies that have examined the effects of fine sediment accumulation on individual taxa. The majority of studies report only changes in macroinvertebrate community structure and abundance (e.g. EPT taxa richness and abundance: Doeg & Koehn, 1994; Kaller & Hartman, 2004; Wood & Armitage, 1999). However, three laboratory-based studies have examined the response of individual taxa to burial by fine sediment (see Dobson et al., 2000; Wood et al., 2005; Wood et al., 2001). Two Trichoptera species from the Limnephilidae family were observed by Dobson et al. (2000) and Wood et al. (2001) and found to be particularly prone to burial, because their sand cases cause them to settle out of drift more rapidly than non case-bearing organisms (Dobson et al., 2000). The responses of an Ephemeroptera nymph (Baetis rhodani), Plecoptera nymph (Nemoura cambrica), Trichoptera larvae (Hydropsyca diae pellucidula) and an isopod (Asellus aquaticus) to burial by sediment were observed by Wood et al. (2005) who found that three out of the four taxa tested were negatively affected by sediment burial. Baetis rhodani was unable to excavate itself from any of the sediment classes tested, A. aquaticus and H. pellucidula became trapped in sediments >2mm and <500µm respectively. Filter feeding macroinvertebrates such as Trichoptera larvae from the Hydropsyca diae family are also likely to be more susceptible to increased sediment accumulation when feeding (Wood et al., 2005). The reduction of interstitial spaces between particles when buried by sediments <2mm in size also leads to a greater mass of sediment being placed on the abdomen of H. pellucidula. As a result, greater effort is required to excavate the body and during this time individuals may be susceptible to predation (Wood et al., 2005). The results of these studies emphasise that macroinvertebrate taxa display individual responses to fine sediment accumulation.

Hydraulics vary spatially in rivers with riffles having faster velocities and pools having slower velocities. Flow rate will affect the rate and amount of fine sediment on the riverbed. Several studies, which have investigated the effect of fine sediment accumulation on macroinvertebrate communities, have focused on faster flowing riffle areas (e.g. Chessman et al., 2006; Culp et al., 1986; Death et al., 2003; Kaller & Hartman, 2004), because of the greater ease involved in macroinvertebrate sampling, large amount of previous data and because this habitat is widely used in bioassessment programs (e.g. AUSRIVAS: Simpson & Norris, 2000). However, slower flowing pool areas may be more sensitive and faster to respond to fine sediment addition than riffle areas because they are depositional sites (Cline et al., 1982; Logan & Brooker, 1983). The effect of sediment runoff from land clearing and urban development on the macroinvertebrate pool fauna of the Murrambidgee River was investigated by Hogg and Norris (1991). They concluded that fine sediment deposition following storm events and the resulting change in substrate composition was the major cause of low macroinvertebrate numbers and species richness in pools. Therefore, it is important to consider the response of macroinvertebrates to fine sediment accumulation from a range of habitats.

Research on the effect of fine sediment accumulation on macroinvertebrates has primarily been based on correlative fieldwork (e.g. Chessman et al., 2006; Death et al., 2003; Hogg & Norris, 1991; Kaller & Hartman, 2004; Quinn & Hickey, 1990). The problem with such studies is that they cannot establish definite causal relationships because of the difficulty of disentangling sediment effects from other changes associated
with intensified landuse (e.g. increased nutrient concentrations, light input or water temperature) (Matthaei et al., 2006). The few manipulative studies that have isolated the effects of fine sediment on macroinvertebrates also reported relatively strong negative effects on macroinvertebrates at small spatial scales. For example, Bond and Downes (2003) used artificial channels 3.6m long and 0.35m wide, and Angradi (1999) used 0.3 m² colonisation trays placed on the streambed. However, a limitation of such small scale experiments is that sedimentation commonly affects long stretches of river. A large-scale field experiment where sand was added to the river bed over 50m river reaches conducted by Matthaei et al. (2006) found that invertebrate taxon richness and richness of EPT taxa was reduced by sediment addition. The experiment was able to disentangle the impact of sediment addition from other land-use effects, such as nutrients and high organic content (Matthaei et al., 2006). Disentangling these effects may enable more specific understanding of the effects of fine sediment accumulation on macroinvertebrates.

Future research needs

Research on the effect of sedimentation on macroinvertebrate communities at a regional scale is required. Previous research in this area has neglected spatial variability in both macroinvertebrate community composition and fine sediment accumulation (Downes et al., 2006). This has been the case in many studies on the ecological effects of stream sedimentation, which have examined single rivers at a reach scale (such as <250m; e.g. Hogg & Norris, 1991; Kaller & Hartman, 2004; Matthaei et al., 2006; Wood & Armitage, 1999). Studies such as Downes et al. (2006) and Harrison et al. (unpublished data), that used several sites throughout catchments, found that there is much spatial variation in both fine sediment accumulation and macroinvertebrate communities that needs to be investigated by collecting replicate macroinvertebrate and sediment samples.

To identify stretches of river ecologically degraded by fine sediment accumulation within a region, future research will need to determine the processes causing fine sediment accumulation, and how macroinvertebrate communities are affected by fine sediment at broad regional scales and local reach scales. At local scales, the spatial variation in composition of macroinvertebrates is driven by their behaviour and the distribution of resources (e.g. food and refuge), which is influenced by substrate characteristics (Boyero, 2003). At larger scales substrate characteristics may affect dispersal. For example, macroinvertebrates may enter drift because of the absence of substrate interstices or appropriate substrates for attachment (Boyero, 2003). Furthermore, at larger regional scales fine sediment accumulation will have a patchy distribution, occurring in areas with the lowest sediment transport capacities (Wilkinson et al., 2006), and resulting in patches of suitable and unsuitable substrate. The potential for fine sediment sensitive macroinvertebrates (e.g. EPT taxa) to colonize areas with suitable substrate will be dependent upon their dispersal capability. It is known that organisms having high dispersal potential (e.g. Hemiptera and Coleoptera, Marchant et al., 2006) can be expected to break down geographical barriers more readily than those which disperse poorly (e.g. fine sediment sensitive Ephemeroptera, Plecoptera and Trichoptera, Marchant et al., 2006) and to occur in all locations where stream physical and chemical characteristics, such as substrate are appropriate (Marchant et al., 2006; Townsend et al., 2003).

Implications for management

The health of aquatic ecosystems is dependent upon its physical habitat and can only be maintained if the ecosystems are protected from degradation. Currently there are no guidelines for assessing the ecological impacts of fine sediment or for protecting the areas of river that may be degraded in the future. This is a major issue considering there are an estimated 30,000 km of streambed degraded by fine sediment accumulation in Australia (Prosser et al., 2001a). Recent developments in assessing the impact of poor water quality on aquatic ecosystems (ANZECC/ARMCANZ, 2000) may provide some direction to this challenge. The water quality guidelines are ecosystem specific and focus on the issues and problems caused by physical, chemical and biological stressors (Hart et al., 1999). For example, they include macroinvertebrate community composition as an indicator of the effects of poor water quality on ecological condition (ANZECC/ARMCANZ, 2000). Such information can then be used to identify ecosystems impaired by water quality and identify appropriate rehabilitation measures for these areas (Hart et al., 1999).

A similar approach may be possible for managing and assessing the ecological impacts of sediment accumulation in rivers. As discussed, we currently know that fine sediment accumulation can result in...
changes to macroinvertebrate community composition. However, further research is still needed to understand the impact of fine sediment accumulation on macroinvertebrate communities at regional scales. Wood and Armitage (1997) suggest a holistic approach for managing sediment accumulation that involves identifying sediment sources and evaluating various management options. The effectiveness of various mitigation measures can then be evaluated in an on-going ecological and physically-based monitoring program (Fig. 1).

Figure 1. A holistic management framework for evaluating the effects of sediment accumulation in rivers (from Wood & Armitage, 1997).

Conclusion

Fine sediment accumulation can cause a loss of abundance and diversity in macroinvertebrate communities (e.g. taxa from the EPT orders). Increases in fine sediment can change the suitability of the substrate for some taxa, increase macroinvertebrate drift and affect respiration and feeding activities. To improve our understanding of the impact of fine sediment on macroinvertebrate communities, research is required on the responses of individual taxa to fine sediment accumulation, the influence of different flow habitats, disentangling its impact from other associated land-uses, and the relationship between fine sediment accumulation and macroinvertebrates at a regional scale. Appropriate guidelines for managing the ecological impact of fine sediment accumulation also need to be implemented to manage its deleterious impacts. This may then aid the managers in implementing appropriate mitigation measures to protect areas from fine sediment accumulation and allow degraded rivers to recover.

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References


