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

Evan T. Harrison[1], Richard H. Norris[2] and Scott N. Wilkinson[3]

1 Institute for Applied Ecology and eWater Cooperative Research Centre, University of Canberra, Bruce ACT 2601. Email: e.t.harrison@student.canberra.edu.au
2 Institute for Applied Ecology and eWater Cooperative Research Centre, University of Canberra, Bruce ACT 2601. Email: richard.norris@canberra.edu.au
3 CSIRO Land and Water, Private Mail Bag PO Aitkenvale QLD 4814. Email: scott.wilkinson@csiro.au

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 km^2). 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 (*Hydropsycidae 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 Hydropsychidae 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 Murrumbidgee 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 m^2 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).

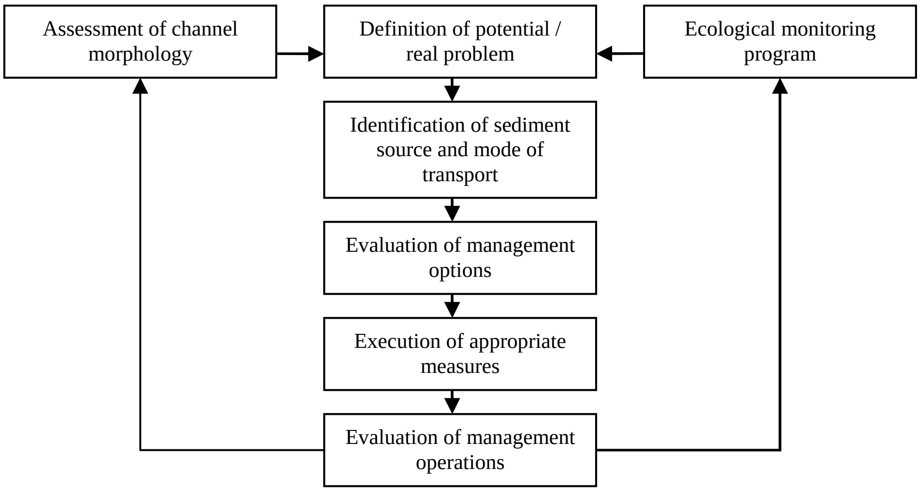

Figure 1. A holistic management framework for evaluating the effects of sediment accumulation in rivers (from Wood & Armitage, 1997).

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.

Acknowledgments

Thanks go the University of Canberra, eWater Cooperative Research Centre, CSIRO Water for a Healthy Country Flagship and River Basin Management Society for providing project funding. Thanks also go to two anonymous reviewers for providing useful comments on the manuscript.

References

Angradi, T. R. (1999). Fine sediment and macroinvertebrate assemblages in Appalachian streams: a field experiment with biomonitoring applications. *Journal North American Benthological Society*, *18*, 49-66.

ANZECC/ARMCANZ (2000). *Australian Water Quality Guidelines for Fresh and Marine Waters. National Water Quality Management Strategy*. Canberra: Australian and New Zealand Environment and Conservation Council and the Agriculture and Resource Management Council of Australia and New Zealand.

Bartley, R., & Rutherfurd, I. D. (2005). Measuring the reach-scale geomorphic diversity of streams: application to a stream disturbed by a sediment slug. *River Research and Applications*, *21*, 39-59.

Bond, N. R., & Downes, B. J. (2003). The independent and interactive effects of fine sediment and flow on benthic invertebrate communities characteristic of small upland streams. *Freshwater Biology*, *48*, 455-465.

Boyero, L. (2003). The quantification of local substrate heterogeneity in streams and its significance for macroinvertebrate assemblages. *Hydrobiologia, 499*, 161-168.
Campbell, I. C., & Doeg, T. J. (1989). Impact of timber harvesting and production on streams: A review. *Marine and Freshwater Research, 40*, 519-539.
Chessman, B. C., Fryirs, K. A., & Brierley, G. J. (2006). Linking geomorphic character, behaviour and condition to fluvial biodiversity: implications for river management. *Aquatic Conservation: Marine and Freshwater Ecosystems, 16*, 267-288.
Cline, L. D., Short, R. A., & Ward, J. V. (1982). The influence of highway construction on the macroinvertebrates and epilithic algae of a high mountain stream. *Hydrobiologia, 96*, 149-159.
Cordone, A. J., & Kelley, D. W. (1961). The influences of inorganic sediment on the aquatic life of a stream. *California Fish and Game, 47*, 189-228.
Culp, J. M., Wrona, F. J., & Davies, R. W. (1986). Response of stream benthos to drift and fine sediment deposition versus transport. *Canadian Journal of Zoology, 64*, 1345-1351.
Death, R. G., Baillie, B., & Fransen, P. (2003). Effect of *Pinus radiata* logging on stream invertebrate communities in Hawke's Bay, New Zealand. *New Zealand Journal of Marine and Freshwater Research, 37*, 507-520.
Dobson, M., Poynter, K., & Cariss, H. (2000). Case abandonment as a response to burial by *Potamophylax cingulatus* (Trichoptera: Limnephilidae). *Aquatic Insects, 22*, 99-107.
Doeg, T. J., & Koehn, J. D. (1994). Effects of draining and desilting a small weir on downstream fish and macroinvertebrates. *Regulated Rivers: Research and Management, 9*, 263-278.
Downes, B. J., Lake, P. S., Glaister, A., & Bond, N. R. (2006). Effects of sand sedimentation on macroinvertebrate fauna of lowland streams: are the effects consistent? *Freshwater Biology, 51*, 144-160.
Graham, A. A. (1990). Siltation of stone-surface periphyton in rivers by clay-sized particles from low concentrations in suspension. *Hydrobiologia, 199*, 107-115.
Harrison, E. T., Norris, R. H., & Wilkinson, S. N. (unpublished data.). University of Canberra and CSIRO Land and Water
Hart, B. T., Maher, B., & Lawrence, I. (1999). New generation water quality guidelines for ecosystem protection. *Freshwater Biology, 41*, 347-359.
Hogg, I. D., & Norris, R. H. (1991). Effects of Runoff and Land Clearing and Urban Development on the Distribution and Abundance of Macroinvertebrates in Pool Areas of a River. *Australian Journal of Marine and Freshwater Research, 42*, 507-518.
Hynes, H. B. N. (1970). *The ecology of running waters*. Liverpool: Liverpool University Press.
Kaller, M. D., & Hartman, K. J. (2004). Evidence of a threshold level of fine sediment accumulation for altering benthic macroinvertebrate communities. *Hydrobiologia, 518*, 95-104.
Lake, P. S. (2005). Perturbation, restoration and seeking ecological sustainability in Australian flowing waters. *Hydrobiologia, 552,* 109-120.
Logan, P., & Brooker, M. P. (1983). The macroinvertebrate fauna of riffles and pools. *Water Research, 17*, 263-270.
Marchant, R., Ryan, D., & Metzeling, L. (2006). Regional and local species diversity patterns for lotic invertebrates across multiple drainage basins in Victoria. *Marine and Freshwater Research, 57,* 675-684.
Matthaei, C. D., Weller, F., Kelly, D. W., & Townsend, C. R. (2006). Impacts of fine sediment addition to tussock, pasture, dairy and deer farming streams in New Zealand *Freshwater Biology, 51*, 2154-2172.
Peckarsky, B. L. (1984). Do predaceous stoneflies and siltation affect the structure of stream insect communities colonizing enclosures? *Canadian Journal of Zoology, 63*, 1519-1530.
Prosser, I. P., Hughes, A., Rustomji, P., Young, B., & Moran, C. (2001a). *Prediction of the sediment regime of Australian rivers.* Paper presented at the Third Australian Stream Management Conference, Brisbane.
Prosser, I. P., Rutherfurd, I. D., Olley, J. M., Young, W. J., Wallbrink, P. J., & Moran, C. J. (2001b). Large-scale patterns of erosion and sediment transport in river networks, with examples from Australia. *Marine and Freshwater Research, 52*, 81-99.
Quinn, J. M., & Hickey, C. W. (1990). Magnitude of effects of substrate particle size, recent flooding and catchment development on benthic macroinvertebrates in 88 New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research, 24*, 411-427.
Rosenberg, D. M., & Resh, V. H. (1993). Introduction to Freshwater Biomonitoring and Benthic Macroinvertebrates. In D. M. Rosenberg & V. H. Resh (Eds.), *Freshwater Biomonitoring and Macroinvertebrates* (pp. 1-9). New York: Chapman and Hall.
Rosenberg, D. M., & Wiens, A. P. (1978). Effects of sediment addition on macrobenthic invertebrates in a northern Canadian stream. *Water Research, 12*, 753-763.

Rutherfurd, I. D. (2000). Some Human Impacts on Australian Stream Channel Morphology. In S. Brizga & B. Finlayson (Eds.), *River Management: The Australasian Experience* (pp. 11-49). Melbourne: John Wiley and Sons Ltd.

Simpson, J. C., & Norris, R. H. (2000). Biological assessment of river quality: development of AUSRIVAS models and outputs. In J. F. Wright, D. W. Sutcliffe & M. T. Furse (Eds.), *Assessing the Biological Quality of Freshwaters: RIVPACS and Other Techniques* (pp. 125-142). Ambelside, UK: Freshwater Biological Association.

Townsend, C. R., Doledec, S., Norris, R., Peacock, K., & Arbuckle, C. (2003). The influence of scale and geography on relationships between stream community composition and landscape variables: description and prediction. *Freshwater Biology, 48*, 768–785.

Waters, T. F. (1995). *Sediment in Streams Sources, Biological Effects and Control*. Maryland, USA: American Fisheries Society.

Wilkinson, S. N., Prosser, I. P., & Hughes, A. O. (2006). Predicting the distribution of bed material accumulation using river network sediment budgets. *Water Resources Research, 42*, 1-17.

Wood, P. J., & Armitage, P. D. (1997). Biological effects of fine sediment in the lotic environment. *Environmental Management, 21*, 203-217.

Wood, P. J., & Armitage, P. D. (1999). Sediment deposition in a small lowland stream: management implications. *Regulated Rivers: Research & Management, 15*, 199-210.

Wood, P. J., Toone, J., Greenwood, M. T., & Armitage, P. (2005). The response of four lotic macroinvertebrate taxa to burial by sediments. *Archiv Fur Hydrobiologie, 163*, 145-162.

Wood, P. J., Vann, A. R., & Wanless, P. J. (2001). The response of *Melampophylax mucoreus* (Hagen) (Trichoptera: Limnephilidae) to rapid sedimentation. *Hydrobiologia, 455*, 183-188.