S&TA Wales

Briefing Paper

The Effects of Excess Fine Sediment in Rivers.

- Excess fine sediment, derived from anthropogenic activities, is a very important cause of deterioration in water and habitat quality and aquatic biodiversity.
- The Water Framework Directive objective of 'good ecological status' cannot be achieved without addressing this pressure.
- Urgent action is required by Defra to identify and use a suitable framework for establishing revised sediment targets for catchment compliance across England and Wales.

Sediment loadings delivered to watercourses originate from a number of upstream primary and secondary sediment sources, including cultivated fields and bank erosion (Collins *et al*., 1997a,b,c). Erosion processes and sediment delivery form an integral part of aquatic systems, influencing their geomorphology, habitat distribution and water quality. Aquatic communities are adapted, and hence able to cope with, natural 'baseline' sediment inputs. Indeed, healthy freshwater ecosystems require sediment inputs to maintain habitat and nutrient fluxes.

However, at a global scale, suspended solid (SS) concentrations in many rivers have dramatically changed in recent years (Walling, 2006). Existing evidence suggests that natural sediment loadings have been substantially exceeded in many catchments in the UK, particularly since World War II (Evans, 2006).

The main anthropogenic activities increasing sediment supply to watercourses include:

- Changes in agricultural practices; for example, increased areas of arable cultivation, leading to greater areas of bare exposed soil susceptible to erosion by winter rainfall (Greig, *et al*., 2005), and mechanised farm practises which compact the soil and increase runoff and soil erosion (McMellin *et al*., 2002: Bilotta, *et al*., 2007). For instance, sediment fingerprinting research indicated 61% of the sediment load of the River Tweed in Scotland was derived from arable and pasture topsoils (Owen *et al*., 2000).
- Intensification of agricultural practices; for example, increasing stock density (Heaney *et al*., 2001) and multiple cropping on arable land.
- Increased bank erosion due to loss of natural hydrology.

Sediment in the water column can be measured in three main ways 1) turbidity; the optical (light scattering) property of the water, 2) total SS; direct measurement of particulate weight present in a volume of water and 3) water clarity; also an optical property of water. Deposited sediment can also be measured using sediment traps. Despite this, there is a distinct lack of SS monitoring data from around the UK, mainly due to cost implications but also a historic perception that other water quality parameters were of greater importance.

Effects of Excess Sediment on Fish and Aquatic Ecosystems

Excessive fine sediment, in suspension or deposited, can have damaging impacts on all life stages of fish, particularly salmonids. This has been made worse for salmonids by a shift in the timings of arable cultivation

in the UK, from spring to autumn sown cereals, which now coincides with their egg incubation times (Collins and Walling, 2007; Collins *et al.,* 2008).
The effect on ecosystems will, however, depend on several key factors, including: the concentration of fine sediment in suspension; the duration of exposure to fine sediment; and the sediment chemical composition and particle size (Bilotta and Brazier, 2008). This makes determining the impact of SS on fauna and flora difficult to generalise, quantify and compare. However, generic consequences of increased SS concentrations in the water column for fish can include:

Physiological effects (stressors on physical health)

- Mortality

  The relationship between SS concentration and direct mortality is highly complex. The effect of sediment on fish will vary depending on life stage, time of year, size of fish, composition of sediment and the availability of off-channel habitat (Bash *et al*., 2001), as well as the exposure magnitude, duration and frequency (Servizi and Martens, 1992). For example, in a review of published critical SS concentration thresholds based on dose-response experiments examining impaired growth, reduced feeding and mortality, Berry *et al*. (2003) reported ranges of 27-80,000 mg l^{-1} for mollusca and 4-330,000 mg l^{-1} for various fish species. Such ranges in the severity of effect of SS concentration are a function of associated stressors including sediment particle size, species life history stage, temperature, the presence of sediment-associated contaminants and sediment load duration (Swietlik *et al*., 2003). Due to the complex interaction of such stressors, it is unlikely that a comprehensive list of genus-based critical SS concentration targets can be developed in the short-term (USEPA, 2003).

- Reduced reproduction and growth through the degradation of spawning habitat/redds and smothering of eggs and yolk-sac fry

  Salmonid eggs (as well as many cyprinid fish and lamprey eggs) require a well-oxygenated environment during the embryonic development stage, so eggs are laid in permeable gravel beds with interstitial pore spaces which allow the passage of oxygenated water. Excess fine sediment in the water, when deposited, can clog these interstitial pores, obstructing the circulation of oxygenated water, which reduces egg survival (Carling, 1984; Magee *et al*., 1996). Salmonid egg mortality of between 98-100% has been recorded within spawning gravels experiencing high siltation loads (Turnpenny and Williams, 1980). The effect is particularly damaging when sediments contain a high organic component, as its subsequent decomposition also reduces oxygen from the water (Rubin, 1995). Excess deposited sediment can also reduce interstitial and hyporheic (region beneath streambed) flow velocities (Chapman, 1988; Acornley and Sear, 1999). This decreases the natural flushing process, which removes the harmful metabolic waste excreted by the embryos (Burkhalter and Kaya, 1975). SS can also be damaging to fish species, such as perch and roach, depositing eggs on macrophytes, as silt particles can adhere to the eggs and reduce oxygen and carbon dioxide exchange (Stuart, 1953).

  Fine sediment can also exert sub-lethal effects on fish fry including: delaying emergence by trapping fry in interstitial pores (Phillips *et al*., 1975); and premature hatching of smaller and poorer quality fry, due to exposure to low dissolved oxygen concentrations (Alderdice *et al*., 1958: Mason, 1969). Researchers have found a relationship between fine sediment (less than 0.850 mm) and fry survival, with decreasing survival of up to 3.4% for each 1% increase in fine sediment (Cederholm *et al*., 1981).

- Gill irritation/trauma

  Fish gills are delicate and easily damaged by abrasive sediment particles. Fish species have been found with increasing levels of deformities, eroded fins, lesions, tumours, gill flaring and ‘coughing’, all related to increasing SS in the water column (Berg, 1982; Schleiger, 2000).

- Alter blood physiology

  Research has show increases in plasma glucose (Servizi and Martens, 1987), blood sugar levels (Servizi and Martens, 1992) and plasma cortisol (Redding *et al*., 1987) in fish species exposed to fine sediment. These are all indicators of stress, and can impact physiological systems, reduce growth and decrease immunological competence against other stressors, such as disease. Stress to salmonids can also affect the smoltication process, leading to decreased osmoregulatory ability, impaired migrations and a reduction in early marine survival (Wedemeyer and McLeay, 1981).

<u>Behavioural (changes in activity)</u>

- Impede movement

Migrating fish species, such as salmonids, are commonly known to migrate through high SS concentrations in estuaries. However, like other containments, exposure time is a key element in the impact of SS as well as concentration (Newcombe and MacDonald, 1991). This means high exposure rates to sediment loads can halt fish migration, particularly upstream. Fish are known to exhibit avoidance reactions and move away from the vicinity of adverse sediment conditions, if refuge conditions are present (Sigler *et al.*, 1984; Bash *et al.*, 2001).

- Alters foraging behaviour and reduces territoriality

Turbidity can reduce feeding rates, and affect prey selection and prey abundance. This is particularly significant for visual feeders, such as salmonids, where SS can reduce the effectiveness of them obtaining food (Berg, 1982). However, research also suggests the turbid-clear water interface may sometimes assist feeding, by offering concealment and protection within the turbid water (Scullion and Edwards, 1980).

Pulses of turbid water have also been shown to breakdown normal social organisation and territoriality, which can decrease feeding rates and may affect overall growth rates (Berg, 1982).

<u>Habitat effects (changes to spawning and nursery habitat):</u>

- Reduction in available spawning habitat

Excess fine sediment, when deposited within rivers, can clog potential spawning gravels, therefore reducing suitable spawning habitat.

- Reduced river bed habitat and shelter for fish fry and parr, leading to lower fry and parr density

The deposition of sediment on the river bed changes and degrades physical habitat for bottom dwelling fish and fry (Lisle and Lewis, 1992). The sediment fills in the spaces between substrate particles, creating a smoother riverbed (Diplas and Parker, 1992). This, not only reduces the available habitat complexity and availability, but also increases water velocity and the need for shelter from the water current (Richardson and Jowett, 2002).

Sedimentation also decreases habitat connectivity (Cohen, 1995) and heterogeneity (Boles, 1981).

<u>Tropic effects</u>:

- Changes in invertebrate communities in response to high and persistent sediment loads (which are well documented) can change food sources, particularly for juvenile salmonids
- Negatively impact invertebrate assemblages and abundances

This occurs through; scour damage, burial of heavy or immobile species, the clogging of gills or feeding structures, and a reduction in interstitial habitat and primary production (Newcombe and MacDonald, 1991).

Benthic invertebrate drift rates have shown to increase in SS concentration as little as 8mg/l (Rosenberg and Wiens, 1978) and population size has been shown to reduce by 77% when exposed to 62 mg/l of SS for 100 days (Wagener and LaPerriere, 1985). A 40% reduction in stream invertebrate species diversity has been recorded in response to prolonged SS concentrations of 133 mg/l over the period of a year (Nuttall and Bielby, 1973)

- Sedimentation can affect aquatic biota at both a population and community level, and result in homogenization; the replacement of regionally distinct faunas with a few invasive and disturbance tolerant species (Walters *et al*., 2003). This could be a serious threat to biodiversity, both now and in the future, by reducing species' resilience to climate change. Sedimentation can also increase the susceptibility of invasive species such as Canadian pondweed and the common carp, which potentially have major disruptive effects on aquatic ecosystems.

In addition to there direct impacts upon fish, suspended sediments, and the consequences of their fall-out in aquatic ecosystems also have a wide range of ecosystem-scale effects which, in turn, have impacts on fish populations. There include:

Transfer of pollutants:

- Fine sediment exerts an important control on the transfer and fate of a wide range of agricultural and industrial contaminants (Warren *et al*., 2003; Collins *et al*., 2005). Sediment therefore represents an important vector for contaminants such as phosphorus (Haygarth *et al*, 2005); heavy metals (Neal *et al*., 1999) and organic pollutants like sheep dip substances (Long *et al*., 1998). These associated pollutants can alter species assemblages by poisoning the water system, and accelerating eutrophication. The capacity of fine sediment to bind contaminants can also lead to an increase in the resident times of the pollutants in aquatic systems (Foster and Charlesworth, 1996), thereby increasing exposure times and the opportunity for pollutant remobilisation.

Reduced primary productivity:

- Suspended solids reduce water clarity and increase turbidity, exerting a negative effect upon primary production. Research suggests in subarctic Alaskan steams concentrations of SS as little as 8mg/l can reduce primary production by 3-13% (Lloyd, 1987), and above 2100 mg/l no primary production can occur (Van Nieuwenhuyse and LaPerriere, 1986).

Depressed oxygen levels in the water:

- Suspended solids can contribute towards raising the Biological Oxygen Demand (BOD; Petts *et al*., 2002), and hence lowered oxygen levels potentially to stressful or lethal levels for vulnerable species and life stages.

Costs of river management:

- Sedimentation increases dredging costs needed to remove sediment for navigation and flood defence purposes (Bates and Hooper, 1997), reduce reservoir capacity (White *et al*., 1996), and increase water treatment costs.

In summary, high concentrations of SS can also negatively impact fish assemblages by reducing; 1) the diversity of sensitive species, 2) overall population abundance, 3) the proportion of lithophilic (associated with a stony substrate) spawners, and 4) the proportion of omnivores (generalist feeders which consume both plant and animal matter) within the overall population. All of these factors can have impacts even at sublethal concentrations of suspended solids, cumulatively reducing the resilience of fish species and hence their resistance to environmental stresses including other forms of pollution, predators, disease and over-exploitation.

Current Management

The current UK standard for SS concentration is set by the EU Freshwater Fish Directive (FFD). The FFD stipulates that SS concentrations should not exceed a guideline annual mean of 25mg/l. This is only a 'guideline' standard which should be achieved where possible. No 'imperative' standards (standards which must be met) currently exist for SS in the UK. In August 2006, UKTAG made the decision to continue running with the guideline threshold in the FFD until this Directive is repealed in 2013.

For the purpose of sediment policy support, a recent modelling study investigated catchment compliance across England and Wales using the FFD guideline standard (Collins and Anthony, 2008a). The study provided the first national scale assessment of sediment sources for England and Wales under current environmental conditions (year 2000), suggesting that source contributions are in the order: agricultural sector (1929 kt = 76%) eroding channel banks (394 kt = 15%), diffuse urban sources (147 kt = 6%) and point source discharges (76 kt = 3%). A structured regression model was used to convert the predicted total sediment loadings into time-averaged suspended sediment concentrations at national scale. The findings suggested that approximately 83% of the total catchment area of England and Wales appears to require no further reductions in sediment loss to rivers from diffuse agricultural sources for the purpose of meeting 'Good Ecological Status' (GES) as defined by the Water Framework Directive (WFD). It is important to note, however, that the use of the FFD sediment threshold failed to identify catchments across England and Wales where the detrimental impacts of sediment are widely reported e.g. the chalk catchments of southern and eastern England. Chalk catchments are particularly vulnerable to sedimentation due to the lack of any significant flushing effect owing to their baseflow-dominated hydrology.

While the agricultural sector in North and most of West Wales is dominated by upland and lowland livestock farming, in much of eastern Wales and parts of south Pembrokeshire arable farming is intensive on valley plains. In the extensive red sandstone areas of the Wye-Usk-Monnow valleys the detrimental impacts of ingress of sediment to watercourses is widely reported; the paucity of post-mayfly flylife on the Monnow, for example, is a serious concern.

Collins *et al.* (2007) used the structured modelling methodology to predict the impact of projected structural evolution in agriculture (land use change) and the uptake of sediment mitigation methods due to programmes like the England Catchment Sensitive Farming Delivery Initiative (ECSFDI) on annual mean suspended sediment concentrations across England and Wales by 2015. This work suggested that structural and mitigation work could potentially reduce the national sediment loss from the agricultural sector by 9% by 2015.

There are, however, serious concerns regarding the use of a single global threshold concentration for suspended sediment. This is because of the large variability of effects caused by SS, the diversity of habitat and conditions within catchments, the existence of sub-threshold effects on both fish and their supporting ecosystems, and the failure of an annual mean to capture the highly episodic nature of sediment pressures which are focused during flood events.

Given the problems associated with using a global annual average sediment threshold, alternative sediment targets were recently proposed for England and Wales. The alternative sediment target scheme (Cooper *et al.*, 2008) is based on nationally extrapolated suspended sediment yields and uses the lower quartile of the measured ranges for catchment types to represent potential targets and the upper quartiles as critical thresholds. These tentative targets are designed to be used in a nested manner and are intended to be used to help inform the identification of local thresholds. Collins and Anthony (2008b) recently used a structured modelling framework taking explicit account of sediment sources derived from different societal sectors to assess catchment compliance at national scale across England and Wales using these alternative sediment targets. This work successfully identified catchments where negative sediment impacts on fish are being reported.

However, the use of sediment yields to represent sediment targets is undermined by a number of problems. Since suspended sediment fluxes represent the aggregate of sediment delivery, their utility is best found in helping to define overall catchment response to environmental pressures as opposed to ecological impacts. Reliable coupling of sediment loadings to ecological impacts requires understanding of additional metrics such as sediment deposition and flushing and sediment grain size characteristics.

It important to highlight that all modelling data is based by common consensus on inadequate knowledge of all pathways and adequate monitoring data assumptions and therefore should not be used in isolation, but as part of an integrated modelling and monitoring approach, to help mange uncertainty and ground truth results. Anecdotal evidence from stakeholders on the impacts of fine sediments upon ecosystem can also provide important insight, and therefore should not be ignored.

Action Required

The evidence here highlights the threats our aquatic fauna and flora face because of excess fine sediment pressures. The WFD objective of GES cannot be achieved without addressing this important pressure. Given the problems associated with using the FFD threshold or the alternative sediment yield based target scheme, urgent action is required to identify more meaningful revised sediment targets for England and Wales. Revised targets must take more explicit account of the impacts of sediment on aquatic ecology and should be developed in a catchment-specific manner (Collins and McGonigle, 2008). A generic measurement of SS is not reliable; therefore we feel SS management should focus on the river basin scale to ensure source control, taking more account of observed impacts rather than modelled inputs.

The S&TA calls for:

- Urgent action by Defra and Welsh Assembly Government to identify and use a suitable framework for establishing revised sediment targets for catchment compliance across England and Wales, taking better account of the impacts of sediment on ecology. This requires a combined modelling and monitoring approach, for which proportionate investment is required to redress historic oversight of the importance of suspended sediment.
- Defra and Welsh Assembly Government to monitor and quantify the efficacy of sediment mitigation options identified in the Inventory of Methods to Control Diffuse Water Pollution from Agriculture (DWPA) User Manual (Cuttle *et al*., 2007) so that mitigation programmes like ECSFDI can be accessed. If quantifiable improvements cannot be shown, further measures (compulsory if necessary) must be put in place, such as water protection zones (WPZ).

Conclusions

Natural sediment pressures within river systems vary dramatically depending on catchment topography, geology, vegetation, local climate and land use (Hicks and Griffiths, 1992). It is now accepted that excess sediment is a very important cause of deterioration in water quality and aquatic biodiversity (Collins *et al*., 2008).

The WFD requires the management of watercourses and their catchments to support high quality and representative biological communities (i.e. GES). In order to achieve this, all major threats to these communities must be monitored and managed effectively as part of a WFD 'Programme of Measures'. Excess fine suspended sediment is a major threat that has been historically underestimated, and therefore must be managed within a framework addressing the multiple pressures influencing water quality and ecological status.

Preventing further damage to river habitats and associated species requires catchment-scale, holistic management, involving the cooperation and regulation of all land users. Managing excess SS requires prevention and restoration measures, all of which require sound understanding of the key sources (Collins and Walling, 2004) and appropriate monitoring to gauge catchment compliance against revised and improved catchment-specific sediment targets. In order for sediment management to progress in England and Wales, better informed sediment targets, and replicable monitoring methods are urgently required for compliance testing.

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