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# Mapping the combined risk of agricultural fine sediment input and accumulation for riverine ecosystems across England and Wales

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ABSTRACT

Fine sediment inputs from agricultural sources are a potential threat to freshwater ecosystems and may impact on the ability of EU members' states to achieve environmental targets under the Water Framework Directive (WFD).

An index (the Agricultural Sediment Risk index or ASR) representing the risk of agricultural fine sediment accumulation in rivers was produced using estimates of sediment inputs from the process-based PSYCHIC model and predictions of fine sediment accumulation using River Habitat Survey data. The ASR was mapped across the entire river network of England and Wales.

The ASR map and index were combined with a national dataset of fisheries surveys using logistic regression to test its relevance to freshwater biota. The ASR was strongly associated with a group of species sensitive to fine sediment inputs including salmon and trout. Another group of species including roach and perch showed a positive association with low levels of agricultural sediment inputs potentially due to their impacts on predators and competitors.

The proposed approach demonstrates how existing national monitoring data and sediment pressure models can be combined to produce an assessment of risk to aquatic ecosystems from agricultural fine sediment sources at a national scale that can be used alongside WFD classification tools to identify potential causative pressures and design remedial actions.



## 1. Introduction

With increasing environmental pressures on rivers and their ecosystems, there is a need for simple, robust tools to support environmental management decision-making (Bainbridge, 2014). In Europe, the Water Framework Directive (WFD) requires member states to bring rivers to Good Ecological Status (GES) between 2015 and 2027 by reviewing existing activities and undertaking targeted remedial action (European Union, 2000).

Agriculture is considered a significant pressure on aquatic ecosystem health through the elevated inputs of nutrients, pesticides, herbicides and sediment and their impact on natural populations of fish, invertebrates, macrophytes and diatoms (Collins et al., 2011; Duerdoth et al., 2015; Gayraud et al., 2002; Jones et al., 2012a, 2014; Kemp et al., 2011). Fine sediment from an agricultural origin currently represents the majority of total fine-grained sediment delivered to watercourses across England and Wales, with an estimated 72–76% of all fine sediment considered to originate from this source (Collins et al., 2009a,b; Zhang et al., 2014).

Fine sediment (defined here as inorganic and organic particles of less than 2 mm in diameter) are known to have both positive and negative impacts on instream ecosystems whether directly (e.g. smothering and clogging) or indirectly (e.g. as vectors for contaminants). They can have direct impacts on fish species by clogging gills, reducing oxygen availability to incubating embryo, increasing stress levels, reducing visibility, carrying pollutants and modifying the morphological structure of habitats (Collins et al., 2011; Kemp et al., 2011; Kjelland et al., 2015). They can also have indirect impact on fish behaviour, feeding, swimming ability and reproduction thereby imposing longer term effects on population structure and resilience (Kjelland et al., 2015). Fine sediment also affects

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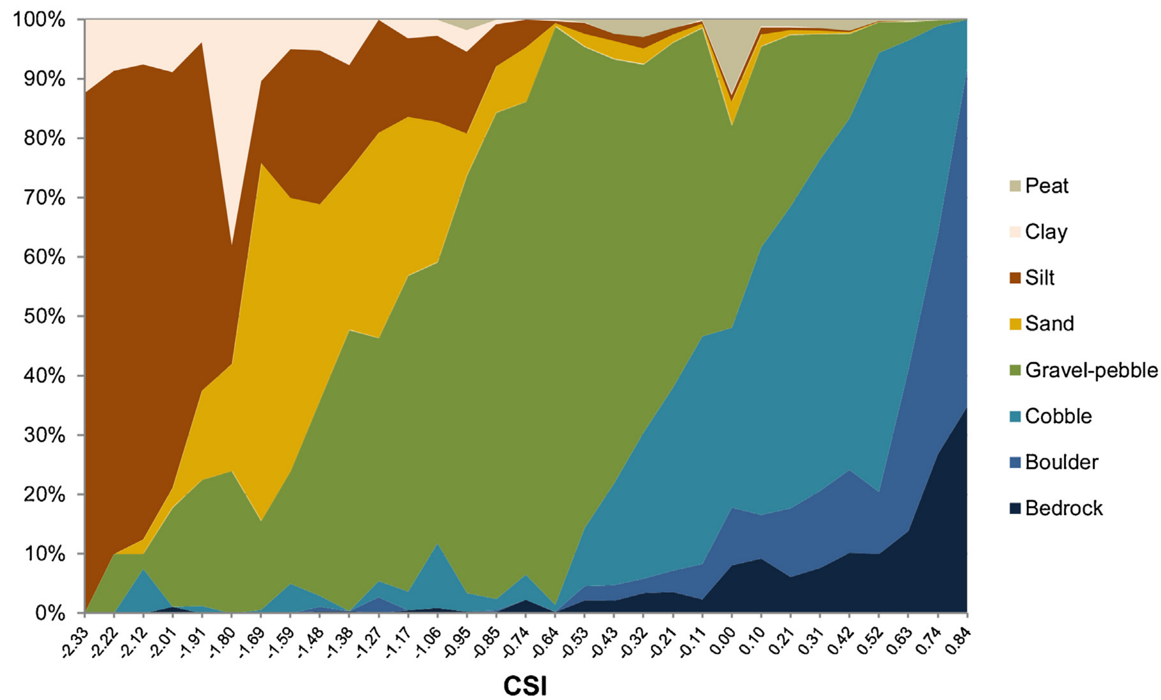


**Fig. 1.** Channel Substrate Index. RHS sites were grouped into 31 bins based on their CSI index value. The graph displays, for each bin, the average occurrence of 8 channel substrate types. Fine sediment (sand, silt, and clay) are dominant at the lower end of the scale and are gradually replaced by coarser sediments as CSI increases.

macro invertebrates via accumulation on and within the river substrate (Jones et al., 2011; Wood and Armitage, 1997), and through increased concentrations within the water column (Gayraud et al., 2002). Channel sediment size is a key element explaining aquatic macrophyte distribution (Gurnell et al., 2010). Fine sediment and macrophytes interact in complex ways. Fine sediment deposition on river margin favours the settlement and growth of emergent vegetation whose leaves, roots and shoots locally reduce flow velocities leading to further sediment entrapment and accumulation (Clarke and Wharton, 2001; Jones et al., 2012a; Sand-jensen, 1998 Sand-jensen, 1998). Fine sediment and macrophyte interaction encourages channel recovery in widened streams through the development of marginal benches and banks and subsequent reductions in channel width (Gurnell, 2014).

The diffuse nature of sediment inputs makes fine sediment management problematic, especially at catchment scale (Collins et al., 2011). The presence and accumulation of fine sediment in streams is dependent on a series of factors, including: precipitation (intensity and total), land management practice (e.g. tillage), the presence of pathways to rivers, channel morphology, channel modifications, impounding structures, flow regime, sediment transported from upstream, and instream vegetation communities (Bilotta et al., 2008; Collins et al., 2009b, 2011). The complex interaction of all these factors makes it difficult to predict accurately where and how much fine sediment will accumulate in a water body and more importantly its origin. As a result, there are no detailed (<10 $km^2$) spatial data characterising fine sediment accumulation across rivers, either globally or nationally.

The effective management of fine sediment is also limited by the structure and nature of existing decision-making. Organisations responsible for policy development, environmental management and the implementation of European directives are subject to continued resource cuts in the face of ongoing economic challenges, meaning that national scale monitoring is constantly being rationalised, thereby increasing the need for robust modelling approaches to support strategic decision-making (Collins and McGonigle, 2008; Naura, 2014). On this basis, there is a need to develop simple modelling tools for predicting agricultural sediment levels in rivers that can be easily applied to fine sediment management by regulatory bodies, and that permit strategic extrapolation in the context of the limited availability of data and knowledge on fine sediment origin and delivery (Bainbridge, 2014; Collins and McGonigle, 2008; Collins et al., 2009c).

One approach that has been widely used in environmental organisations is risk assessment. Risk assessment is one means of identifying potential levels of threats posed by contaminants based on data, models or expert opinion (Fairman et al., 1999). Risk levels can easily be represented in the form of maps and communicated to all stakeholders (Zerger, 2002). In the absence of specific or accurate data sources and knowledge, risk assessment may provide a meaningful way of supporting decision-making using existing resources (Jones, 2001). To the users, the relative simplicity and openness of outputs and derivation process may bring clarity and transparency and foster trust.

In this paper, we develop a risk-based approach towards assessing the likelihood that accumulated fine sediments on the river bed are of agricultural origins and we test the resulting fine sediment index on existing biological monitoring data. We choose fine sediment accumulation rather than concentration within the stream, for the following reasons: (a) data on fine sediment accumulation on the stream bed are more widely available and relatively simple to measure; (b) accumulation represents both the concentration of fine sediment in the water column and the deposition rate of entrained sediment, and; (c) it has been shown to be a major cause of change in biological communities (Jones et al., 2012a, 2014, 2012b).

The risk of fine sediment accumulation was assessed by combining a map of fine sediment distribution produced with spatially explicit predictive models based on existing River Habitat Survey (RHS) data (Naura et al., 2016), with a map of agricultural fine sediment inputs derived from the sediment module of the process-based ADAS Pollutant Transport (APT) framework (Collins et al., 2012b; Davison et al., 2008; Zhang et al., 2014). The correlation between the final risk map and aquatic biota was tested statisti-