Agriculture, Ecosystems and Environment 179 (2013) 41–52

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Predicting critical source areas of sediment in headwater catchments

Joshua Thompson[a,b,*], Rachel Cassidy[b], Donnacha G. Doody[a], Ray Flynn[b]

[a] Agriculture, Food and Environmental Science Division, Agri-Food and Biosciences Institute, 18a Newforge Lane, Malone Upper, Belfast, Northern Ireland, UK
[b] Groundwater Research Group, The Queen's University of Belfast, David Keir Building, Stranmillis Road, Belfast, Northern Ireland, UK

ARTICLE INFO

Article history:
Received 3 December 2012
Received in revised form 15 July 2013
Accepted 22 July 2013
Available online 24 August 2013

Keywords:
Diffuse pollution
Hydrological connectivity
Critical source areas
Monte Carlo
Sediment source fingerprinting
Suspended sediment

ABSTRACT

Mitigation of diffuse nutrient and sediment delivery to streams requires successful identification and management of critical source areas within catchments. Approaches to predicting high risk areas for sediment loss have typically relied on structural drivers of connectivity and risk, with little consideration given to process driven water quality responses. To assess the applicability of structural metrics to predict critical source areas, geochemical tracing of land use sources was conducted in three headwater agricultural catchments in Co. Down and Co. Louth, Ireland, within a Monte Carlo framework. Outputs were applied to the inverse optimisation of a connectivity model, based on LiDAR DEM data, to assess the efficacy of land use risk weightings to predict sediment source contributions over the 18 month study period in the Louth Upper, Louth Lower and Down catchments. Results of the study indicated sediment proportions over the study period varied from 6 to 10%, 84 to 87%, 4%, and 2 to 3% for the Down Catchment, 79 to 85%, 9 to 17%, 1 to 3% and 2 to 3% in the Louth Upper and 2 to 3%, 79 to 85%, 10 to 17% and 2 to 3% in the Louth Lower for arable, channel bank, grassland, and woodland sources, respectively. Optimised land use risk weightings for each sampling period showed that at the larger catchment scale, no variation in median land use weightings were required to predict land use contributions. However, for the two smaller study catchments, variation in median risk weightings was considerable, which may indicate the importance of functional connectivity processes at this spatial scale. In all instances, arable land consistently generated the highest risk of sediment loss across all catchments and sampling times. This study documents some of the first data on sediment provenance in Ireland and indicates the need for cautious consideration of land use as a tool to predict critical source areas at the headwater scale

1. Introduction

Delivery of fine suspended sediment (SS) can cause the disruption of food-web structures via both top-down and bottom-up impacts. These may include negative impacts on salmonids throughout their lifecycle (Lake and Hinch, 1999; Suttle et al., 2004; Heywood and Walling, 2007), a reduction in invertebrate grazers (Kiffney and Bull, 2000), the restriction of periphyton growth (Yamada and Nakamura, 2002), and facilitating phosphorus (P) delivery, leading to eutrophication (Kronvang et al., 1997; Quinton et al., 2001). Although mobilisation and transfer mechanisms of fine sediment are well defined (Bilotta et al., 2007), knowledge of how these processes operate within the landscape to produce stream response is limited by poor understanding of the spatial scale dependency of mobilisation and delivery processes (Haygarth et al., 2005a, 2012). Nevertheless, many studies have used the concept of hydrological connectivity to explain SS and P delivery at the catchment (Russell et al., 2001; Deasy et al., 2011), hillslope (Dahlke et al., 2012), and process level (Doody et al., 2006). Moreover, occurrence of nutrient rich and erodible sources on areas with a high propensity for hydrological connectivity to the drainage network, are hypothesised to result in critical source areas (CSAs) (Schulte et al., 2009). Targeting mitigation measures at CSAs have been argued to provide a basis for cost effective protection and improvement in the chemical and biological quality of water bodies, to fulfil regulatory requirements such as the EU Water Framework Directive where good and high ecological status needs to be achieved and sustained (Doody et al., 2012; EC, 2000).

Prediction of CSAs has traditionally followed the transfer continuum proposed by Haygarth et al. (2005b), working from contaminant source to surface water receptor (Srinivasan and McDowell, 2009; Marjerison et al., 2011; Wall et al., 2011). However, this often leads to definition of catchment scale risk in terms of its structural connectivity (i.e. connectivity potential determined by the distribution of landscape features); consideration of

* Corresponding author at: Agriculture, Food and Environmental Science Division, Agri-Food and Biosciences Institute, 18a Newforge Lane, Malone Upper, Belfast, Northern Ireland, UK. Tel.: +44 02890 255490.
E-mail addresses: jthompson59@qub.ac.uk, joshuajamesdavidthompson@gmail.com (J. Thompson).

0167-8809/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agee.2013.07.010

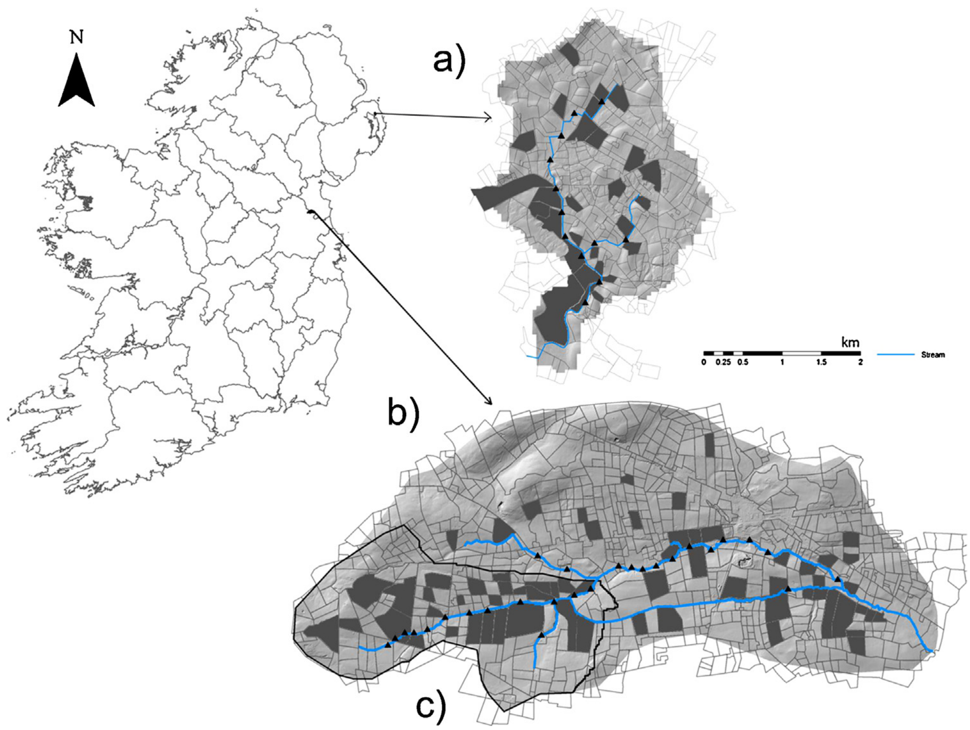

Fig. 1. Location of (a) Down Catchment, (b) Louth Lower Catchment and (c) Louth Upper Catchment within Ireland showing field boundaries. Dark outline in Louth Catchment indicates the Louth Upper sub catchment. Fields and woodland areas sampled for top soils are indicated by dark grey shading and channel bank faces sampled are indicated by black triangles.

functional connectivity (i.e. connectivity determined by dynamic temporal processes such as rainfall characteristics) is often implicit (Turnbull et al., 2008; Lexartza-Artza and Wainwright, 2009).

Although structural and functional connectivity are linked through feedbacks, structural connectivity may not lead to a functional response and the influence of structural connectivity can change seasonally in response to catchment wetness (Jencso and McGlynn, 2011). In this respect there has been a recent emphasis on the need to understand the functional aspects of connectivity (Wainwright et al., 2011), and to define CSAs by working up the transfer continuum from impact to source, thereby switching the distribution of risk a priori to a posteriori (Reaney et al., 2011). This approach provides a basis to define CSA risk through understanding catchment-specific ecosystems and their response to the timing and duration of exposure to pollutants (Bilotta et al., 2012).

While the understanding of functional connectivity is necessary at the hillslope and field scale, to elucidate the process rules governing SS and nutrient transfer, its wider impact on catchment and river basin scale processes also needs to be considered. Linking these two spatial scales remains one of the greatest challenges in catchment science (Haygarth et al., 2012), particularly when perceived source risk on the landscape (such as soil P indices) may not equate to proportional risks in-stream (Jordan et al., 2012).

In recognition of this, there has been a shift from studying complexity in catchment hydrological response, towards an understanding of attributes driving similarity, such as soil type and land use (Ali et al., 2012). Equally, attributes driving similarity in water and biological quality have also been studied within large catchments (Donohue et al., 2006; Rothwell et al., 2010; Tetzlaff et al., 2012). In many instances, structural attributes such as land use can predict water quality at large catchment scales, however these metrics need to be tested at sub-catchment scales, as it is at this level where interaction with stakeholders will take place and supplementary measures will be implemented (Doody et al., 2012). Similarly, processes and transfers at sub-catchment scale may also undermine ecological integrity at wider catchment to regional scale (Freeman et al., 2007).

The objectives of this study were to (1) evaluate the applicability of land use risk weightings to predict critical source areas at the headwater scale, where mitigation measures are typically implemented, and (2) assess whether variation in structural connectivity can explain functional variances in sediment delivered from catchment land use sources.

2. Methods

2.1. Study sites

Research was conducted in three agricultural headwater catchments in Co. Down, Northern Ireland (+54° 32′ N, −5° 35′ E) and Co. Louth, Republic of Ireland (+53° 45′ N, −6° 27′ E) (Fig. 1). The Down catchment drains 7.52 km^2 of low lying land (0–60 m OD) into Strangford Lough. The Louth catchment, which was examined at two spatial scales, drains 20.96 km^2 in total (Louth Lower), with elevations of 80–220 m, and is a tributary of the River Boyne, flowing east into the Irish Sea. A sub-catchment of 5.4 km^2 (Louth Upper) was defined in the southwest of the main catchment. Table 1 details the land use classifications for the three sub-catchments, indicating the dominance of grassland in all catchments, which is typical of Irish agricultural systems.

Soils within the Down Catchment were comprised of gleysols and stagnosols (42.5%), leptosols (41.5%), fluvisols and fluvisols with histic horizons (14.8%), histosols (0.6%) and cambisols (0.6%). The Louth catchments were also dominated by gleysols (72.3%), with the remainder comprising of leptosols and regosols (13.6%), cambisols (8.9%), fluvisols (4.4%), artificial materials (0.7%) and podsols (0.1%).

Both sites are underlain by greywacke (Silurian and Ordovician turbidite successions) overlain by glacial tills in the form of drumlins in the Down Catchment and by a more complex