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River rehabilitation for the delivery of multiple ecosystem services at the river network scale

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ABSTRACT

This paper presents a conceptual framework and methodology to assist with optimising the outcomes of river rehabilitation in terms of delivery of multiple ecosystem services and the benefits they represent for humans at the river network scale. The approach is applicable globally, but was initially devised in the context of a project critically examining opportunities and constraints on delivery of river rehabilitation in Scotland. The spatial-temporal approach highlighted is river rehabilitation measure, rehabilitation scale, location on the stream network, ecosystem service and timescale specific and could be used as initial scoping in the process of planning rehabilitation at the river network scale. The levels of service delivered are based on an expert-derived scoring system based on understanding how the rehabilitation measure assists in reinstating important geomorphological, hydrological and ecological processes and hence intermediate or primary ecosystem function. The framework permits a "total long-term (>25 years) ecosystem service score" to be calculated which is the cumulative result of the combined effect of the number of and level of ecosystem services delivered over time. Trajectories over time for attaining the long-term ecosystem service score for each river rehabilitation measures are also given. Scores could also be weighted according to societal values and economic valuation. These scores could assist decision making in relation to river rehabilitation at the catchment scale in terms of directing resources towards alternative scenarios. A case study is presented of applying the methodology to the Eddleston Water in Scotland using proposed river rehabilitation options for the catchment to demonstrate the value of the approach.

Our overall assertion is that unless sound conceptual frameworks are developed that permit the river network scale ecosystem services of river rehabilitation to be evaluated as part of the process of river basin planning and management, the total benefit of river rehabilitation may well be reduced. River rehabilitation together with a 'vision' and framework within which it can be developed, is fundamental to future success in river basin management.

1. Introduction

The value of intact aquatic and terrestrial ecosystems, in the form of ecosystem services was established in the 1990s (e.g. Constanza et al., 1997; Daily, 1997; Postel and Carpenter, 1997). Ecosystem services here are defined as "quantifiable or qualitative benefits of ecosystem functioning to the overall environment, including the products, services and other benefits humans receive from natural, regulated, or otherwise perturbed ecosystems" (Thorpe et al., 2006). The ecosystem service concept has been brought to the fore post 2000 by the Millennium Ecosystem Assessment (Millennium Assessment, 2005), which recognised four such categories of ecosystem service – supporting [food (crops & livestock products); biomass (fibre & energy materials); water for use (supply, irrigation, cooling etc); navigation; and health products], regulating (carbon regulation; water flow & flood regulation; water quality regulation; human health regulation), provisioning (biodiversity; soil formation; nutrient recycling) and cultural (science & education; tourism & recreation; sense of place and history). More recently, in the UK the National Ecosystem Assessment (UK National Ecosystem Assessment, 2011) extended this concept to show the link between primary ecosystem processes (such as primary production, nutrient and water cycling), their associated final ecosystem services (crops, water supply, climate regulation, etc.) and the goods and benefits that humans derive from them

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(including food, energy, drinking water, flood control, recreation and aesthetics). Key to understanding these links is the role of biodiversity and land use management underpinning ecosystem functioning and services (Haines-Young and Potschin, 2010).

There is now widespread recognition of the fact that river systems in their natural state provide to humans a range of ecosystem goods and services. However hundreds of years of modifications in fluvial corridors and the catchments they drain have altered the nature of ecosystem services. In degraded river systems, many such primary ecosystem processes are negatively affected and the cumulative total of ecosystem goods and services they provide to society has clearly been diminished They have been degraded or lost to provide food and other (provisioning) services incompatible with their original ecosystem functioning and the regulating, cultural and supporting services they provided in their intact state (Posthumus et al., 2010). The integrity of such systems has been diminished through human activity impacting on flow, quality and structure of water courses, from diffuse pollution and invasion by non-native species. Indeed the Millennium Ecosystem Assessment (Millennium Assessment, 2005) suggests that inland water ecosystems are probably the most affected of habitats by historical changes.

In the UK, monitoring for the European Water Framework Directive (WFD) shows that, along with diffuse pollution, changes to flow regime and to hydromorphology form the main biophysical drivers of ecosystem alteration of freshwaters and wetlands (UK National Ecosystem Assessment, 2011). River rehabilitation provides an opportunity to restore ecosystem services that have been degraded and lost and to create a well balanced relationship between riparian landowners and residents and naturally functioning river systems. As such, in the USA billion of dollars are spent on river restoration (Bernhardt et al., 2007), with increasing amounts being directed towards river restoration in European countries such as Denmark and England. Globally, ecosystem services assessment has seen an increase in attention within conservation planning since the turn of the century (Egoh et al., 2007).

1.1. Justification for the multiple ecosystem services approach

The potential multiple benefits of investing in rehabilitation of the physical habitat of rivers are widely recognised (Palmer and Allan, 2006; Palmer and Filoso, 2009; Arthrington et al., 2009). The activity of river rehabilitation, however, has rarely been given significant resources, primarily because the multiple benefits that it can achieve have not been well established and a scientific evidence base is lacking. Rivers have the potential to provide a variety of regulating, provisioning and cultural services, but many of these are non-market or public goods (rather than more easily measured private goods, such as agricultural production), and do not command prices that are readily valued (UK National Ecosystem Assessment, 2011). Consequently, these services have largely been ignored when making decisions about managing river and catchments, despite the development of new valuation techniques (see for example Turner et al., 2008). In addition, many of these other service benefits are not necessarily enjoyed within the same location, timescale or by the same communities as the inherent associated costs. Finally, where studies of economic benefits of ecosystem service provision have been done, they have tended to be very intensive, topic, context and location-specific (Turner et al., 2008; Liu et al., 2010; Norgaard, 2010), and without the development of an effective simple framework or tool for operational implementation. In this context, Cook and Spray (2012) have highlighted the common features of the implementation challenge faced by both ecosystem services and integrated water resource management.

1.2. River rehabilitation at the network scale

River rehabilitation globally and historically has largely been aimed at the reach-scale and directed primarily at biodiversity and fisheries improvement. This no doubt reflects in part the inability of early practitioners to consider or to tackle multiple and complex issues that would otherwise require a more holistic and river network wide approach, as well as the means to engage with socio-economic concepts in decision-making for river rehabilitation (Reichert et al., 2007) Few scientific studies however have yet to demonstrate the river corridor network-wide benefits of these smaller rehabilitation schemes. For example, Kondolf (2000) in California has observed that uncoordinated piece-meal rehabilitation can have questionable ecosystem-wide benefit, and one should rather consider the idea of catchment scale river rehabilitation. River network scale river rehabilitation is defined here as “any river rehabilitation activity that singly, or in combination, restores natural processes and a naturally functioning ecosystem and brings benefit or environmental services to much of the wider river network and not just to the site of rehabilitation”. Similarly, with flood risk regulation, Blanc et al. (2012) have reviewed studies of river restoration projects to achieve desynchronisation of flood peaks to show that in some instances small scale restoration schemes in upper parts of catchments may actually, in combination, lead to no better, if not worse delivery of flood regulation downstream.

Currently it appears as if few organisations and countries globally have developed frameworks and strategies to optimise integrated delivery at the catchment scale (Ormerod, 2004; Nilsson et al., 2007), though an increasing number of potential policy drivers exist to take this forward (Mainstone and Holmes, 2010; Battarbee et al., 2008). More generally, in terms of ecosystem conservation the development of coherent strategies has been stressed as essential (Rozdilsky et al., 2001; Roni et al., 2002, 2008; Wainger et al., 2010), together with strategies for identifying and prioritising actions (Beechie et al., 2008, 2009). Transparency in the decision-making process is also important to support consensus-building among stakeholders (Reichert et al., 2007) and to quantify and explore strategic regional priorities (Bryan et al., 2010).). Linking ecosystem services and river rehabilitation to hydrogeomorphic classification of rivers is one of the few attempts at initiating a framework (Thorpe et al., 2006). Hillman and Brierley (2005) also argue the need for a biophysical vision at the catchment scale to achieve mature progress in stream rehabilitation.

1.3. European policy background to river network scale river rehabilitation

Within Europe, member states are working towards a national strategy to deliver good ecological status to their rivers under the European Union Water Framework Directive obligations. As part of this, it mandates the understanding of the benefits of attaining good ecological status on rivers via river rehabilitation. Some, member states such as Austria, Denmark, Germany and the Netherlands have already identified significant funds to take forward large scale rehabilitation, often on the back of flood risk reduction, though not without considerable public opposition (Buijs, 2009). Within England and Wales, the Environment Agency in 2012 announced a Catchment restoration fund to address the issues of water bodies failing good ecological status. However, these are mainly focussed at single issues such as diffuse pollution and how they will assist in delivery of multiple ecosystem services is largely unknown. The Environment Agency is however producing guiding principles for morphologically based river rehabilitation to guide planning and prioritisation at the catchment scale to deliver