Ecological Engineering 65 (2014) 62–70

Contents lists available at ScienceDirect

Ecological Engineering

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

From ecosystems to ecosystem services: Stream restoration as ecological engineering

Margaret A. Palmer[a,b,c,*], Solange Filoso[c], Rosemary M. Fanelli[c,d]

[a] Department of Entomology, University of Maryland, College Park, 4112 Plant Science Building, College Park, MD 20742, United States
[b] National Socio-Environmental Synthesis Center (SESYNC), 1 Park Place, Suite 300, Annapolis, MD 21401, United States
[c] Chesapeake Biological Lab, University of Maryland Center for Environmental Science, 1 Williams Street, Solomons, MD 20688, United States
[d] Marine, Estuarine, and Environmental Science Graduate Program, University of Maryland, College Park, 1213 HJ Patterson Hall, College Park, MD 20742, United States

ARTICLE INFO

Article history:
Available online 30 July 2013

Keywords:
Ecosystem services
Streams
Restoration
Stormwater
Ecological engineering
Nitrogen
Suspended sediment

ABSTRACT

Ecosystem restoration was originally founded upon recovering ecosystems using wildlands as a reference state. More recently there has been interest in shifting to the restoration of ecosystem services – the benefits that natural systems can provide to humans. This shift is resulting in new restoration goals as well as new methodological approaches. The pace at which restoration goals and methods are changing is particularly fast for running-water ecosystems, which calls for a rigorous assessment of the environmental and economic costs and benefits associated with such changes.

In this paper, we explore the environmental costs and benefits of an emerging form of urban stream restoration, in which ecosystems are vastly transformed in order to enhance specific ecosystem functions and support desirable services. These projects are usually implemented in highly incised low-order perennial, intermittent, or ephemeral stream reaches. In either case, the stream channel is transformed into a stormwater management structure designed to reduce peak flows and enhance hydraulic retention of stream flow with the goals of reducing bank erosion and promoting retention of nutrients and suspended sediments. Results to date indicate that this novel ecological design approach does modify the hydrologic responses of streams during some storm events, but there is no consistent pattern of nitrogen retention or removal that would lead to net annual benefits. While additional data are needed, results suggest there is the potential for sediment retention, at least during some flows. Ongoing work which includes monitoring both pre- and post-project implementation will help resolve this uncertainty.

If sediment retention does occur, it is likely to decrease over time making the lifespan of these highly engineered projects is finite. Furthermore, environmental impacts associated with these projects can include loss or damage of riparian forests and export of sediment pulses during construction which may offset project benefits depending on their lifespan. Therefore, the use of approaches where entire existing ecosystems are modified to enhance a few specific biophysical processes should be limited to the most degraded systems where less invasive techniques, such as upland reforestation, reduced lawn fertilization, or better stormwater management at the source of runoff generation have first been exhausted.

1. Introduction

The concept of ecosystems as life-support systems and as providers of goods and services that have quantifiable value has now become widely adopted by the scientific and management communities (Cowx and Aya, 2011). The concept has been extremely useful in educating the public about our reliance on natural systems, but it also has implications for the science and practice of restoration. Historically, the focus of restoration ecology was on how best to recover "wildlands," and the choice of reference systems or a nearby least disturbed ecosystem of similar type for guiding restoration was typically a prior condition (Swetnam et al., 1999; White and Walker, 1997). Of course, the use of such references for restoration has been challenged by two persistent questions: What past? When has a system been free of human disturbance?

These questions are particularly germane given the dramatic changes in land use that have occurred worldwide and the potential

---

[*] Corresponding author at: National Socio-Environmental Synthesis Center (SESYNC), 1 Park Place, Suite 300, Annapolis, MD 21401, United States. Tel.: +1 410 919 4810.
E-mail address: mpalmer@umd.edu (M.A. Palmer).

0925-8574/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ecoleng.2013.07.059

impacts of climate change (Davies, 2010). But, if a wildlands concept was not to guide restoration efforts, ecologists had to come up with an alternative. A variety of options have been proposed, including restoration targeting the historical range of variability (Morgan et al., 1994) or some guiding image of that (Palmer et al., 2005), restoration to maximize biodiversity or recover a valued species (Feld et al., 2011), and restoration to recover lost ecosystem processes (Beechie et al., 2010). For river systems in particular, Dufour and Piegay (2009) suggest the use of a restoration framework that incorporates both the historical context of a site (and its potential functions as observed in reference sites) as well as the societal needs for that site when developing restoration objectives. This is an appealing perspective but may be particularly difficult to achieve since current societal needs may conflict with the services an ecosystem provided historically (Sanon et al., 2012).

At the same time that restoration ecologists were broadening perspectives on goals and guidelines for restoration, the formalization and rise in broad use of the ecosystem services concept was occurring (MEA, 2005). Initially, the term “ecosystem services” meant essentially the benefits of nature to households, communities, and economies, and most attention was placed on the valuation of these ecosystem services. More recently, however, understanding when and where specific services are produced has become of great interest in the environmental management community (Daily et al., 2009). Whereas the ecosystem services concept largely arose independent of the concept of ecological restoration, we suggest they are increasingly intersecting. An ecosystem services framework does provide a new way to think about restoration goals and interventions. However, the very act of categorizing services implies an independence of the different components that support an ecosystem (e.g., soils, wetlands, forests) and the processes that sustain it (e.g., carbon cycling, primary production) (Muridan and Rival, 2012). This assumption combined with separate valuation of components and processes (Mehan, 2009) and emerging markets for restoration of specific services has placed additional pressure on ecologists to identify which biophysical processes and ecosystem components must be restored to recover specific ecosystem types and functions (Palmer and Filoso, 2009). If we understand these relationships well and a specific service is desired then restoration can target the subset of processes and components that will lead to the production of that service; however, targeting only a subset could limit the provision of other ecosystem services (Gilvear et al., 2013). For example, work by Sanon et al. (2012) indicated that restoration specifically targeting hydraulic connectivity of an Austrian floodplain would provide habitat for native biodiversity but reduce the provision of drinking water for local citizens. There are also a number of studies that have shown loss of terrestrial ecosystem services related to biodiversity or the provision of water when reforestation restoration is undertaken to enhance carbon sequestration (Hall et al., 2012; Jackson et al., 2005).

The concept of restoration of ecosystem services differs from single- or multi-species management in that the former necessarily is focused on the human use or desire for the service, whereas the latter is often but not necessarily motivated by utilitarian objectives. In both cases, however, concerns have been raised over the potential loss or degradation of ecosystem attributes that are not the focus of management or restoration efforts. Despite these concerns, the trend to focus on ecosystem services as part of ecological restoration and management is increasing (Trabucchi et al., 2012). Oyster restoration has been recommended as a strategy to help reverse eutrophication in coastal waters, and the costs and benefits of forest and wetland restoration are increasingly being evaluated in an ecosystem services framework (Birch et al., 2010; Cerco and Noel, 2007; Jenkins et al., 2010). Adoption of this framework seems to be happening at a particularly rapid pace with respect to running-water ecosystems, in part because of the potential linkage of stream restoration to environmental mitigation markets, but also because of the strong human dependency on the services that rivers provide (Doyle and Yates, 2010; Palmer, 2009). To illustrate how ecological restoration can shift from efforts to recover whole ecosystems and the full suite of their services to efforts undertaken to recover specific attributes or processes, we focus below on Coastal Plain streams. However, this phenomenon is not unique to running-water systems. Similar shifts can be found in very different types of ecosystems and parts of the world (e.g., forest restoration shifting to managed timberland for carbon offsets (Ecotrust, 2013); biodiversity conservation and restoration shifting to habitat creation for selected bird species (Morris et al., 2006)).

2. Running-water ecosystems and restoration

Streams and their floodplains provide ecosystem services essential to human well-being (Palmer and Richardson, 2009), and have become increasingly managed to optimize these services (Tockner et al., 2011). As a result, the rate of biodiversity loss in running waters exceeds that of terrestrial and marine systems and the water quality status of the world’s rivers is declining; this is particularly evident in urban areas. Urban expansion is a major global issue (Seto et al., 2011). In some countries, point-source inputs of untreated wastewater are significant and throughout the world, nonpoint-source pollution is pervasive (Corcoran et al., 2010). Runoff from impervious surfaces has a very large impact on stream and river discharge, and in some cities the rapid routing of stormwater directly to streams exacerbates peak flows and pollutant loads (Walsh et al., 2005). Higher and more frequent peak flows can also erode stream channels (Booth and Jackson, 1997) and result in high levels of fine sediments transported to downstream waters (Paul and Meyer, 2001), which can also increase the flux of N to coastal waters (Mayer et al., 1998).

A variety of management tools are being used to address urban stream and river impairment, including better development practices, separation of stormwater and sewer systems, and riparian and wetland restoration (Walsh et al., 2005). Unfortunately, the costs associated with these projects are enormous, and jurisdictions through the U.S., Europe, Australia and other regions of the world simply cannot fund all of the needed remediation projects. Further, implementing projects in developed watersheds often involves the difficult task of working with many private-property holders to gain access to buried or difficult-to-reach structures. For these reasons, alternative approaches to correcting the underlying cause of degradation for most urban streams and rivers – uncontrolled non-point inputs – are of great interest. Search for alternative approaches to control non-point inputs has increasingly led to direct alteration of stream channels in an attempt to restore them, even though the U.S. Clean Water Act limits certain activities within streams. Impacts to ‘waters of the United States’ including any dredging or filling require permits from the U.S. Army Corps of Engineers and permittees must compensate for these impacts by restoring streams elsewhere or by purchasing credits from stream mitigation banks (Lave et al., 2010).

2.1. Process-based restoration to ecological engineering

Restoration as a management tool for improving the health of rivers and streams has grown dramatically in the last decade (Bernhardt et al., 2005; Feld et al., 2011). Indeed, it is a mandatory element of the European Framework Directive which commits EU states to achieve “good status” for their ground and