Ecosystem Services 10 (2014) 1–5

Contents lists available at ScienceDirect

Ecosystem Services

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

Beyond the concrete: Accounting for ecosystem services from free-flowing rivers

Daniel A. Auerbach[a,*,1], Daniel B. Deisenroth[b,2], Ryan R. McShane[a], Kevin E. McCluney[c,3], N. LeRoy Poff[a]

[a] Graduate Degree Program in Ecology, Colorado State University, Fort Collins, CO, USA
[b] Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, CO, USA
[c] Natural Resource Ecology Laboratory, Colorado State University and US Geological Survey, Fort Collins Science Center, Fort Collins, CO, USA

ARTICLE INFO

Article history:
Received 11 July 2014
Accepted 23 July 2014

Keywords:
Rivers
Dams
Water infrastructure
Integrated assessment
Environmental flow regime

ABSTRACT

People derive benefits from river networks under free-flowing conditions, through ecosystem services such as fishery yield, floodplain agriculture, desirable geomorphic form, and the cultural significance of native riverine biodiversity. However, water management decisions have historically emphasized the production of ecosystem services such as hydropower and irrigation that depend on the construction of extensive infrastructure. Such decisions typically impose tradeoffs that reduce benefits from free-flowing services, yet neither these losses nor the costs of future ecosystem rehabilitation have been well represented in decision support analyses. Ecosystem service assessments can and should account for benefits in the absence of water infrastructure to inform balanced water policy and watershed management.

1. Beyond infrastructure-dependent services

Freshwater availability is a fundamental driver of local economies and ecosystem states, and societies have depended on rivers for millennia (Wohl, 2010; Fagan, 2011). Governments, corporations, and communities can and should account for a diverse portfolio of river-derived ecosystem services as they decide how best to manage surface water resources in the challenging context of global climate change and population growth (Engel and Schaefer, 2013; Ormerod, 2014). Such accounts may reveal choices that sustain desired ecosystem functions while delivering equitable economic gains (Fisher et al., 2008; Ruckelshaus et al., 2014). Yet, ecosystem service assessments must account for more than water uses that rely on dams, levees, and diversion channels if they are to adequately characterize tradeoffs in watershed management.

Industrial-scale interventions and infrastructure within river corridors have played a fundamental role in historic trends of economic development, and "hydrologic ecosystem services" such as hydropower and out-of-channel water supply to irrigators, municipalities, and private firms have received considerable attention within the burgeoning field of research on ecosystem services (Brauman et al., 2007). For example, programs of payment for watershed services often involve infrastructure owners compensating upstream stakeholders to modify their agricultural and forestry practices in ways that are intended to secure profitable operations and intact terrestrial habitats (e.g., by reducing reservoir sedimentation or dampening discharge fluctuations; Guo et al. (2000, 2007); Martin-Ortega et al. (2013); Wunder (2013); Fu et al. (2014). However, extensive water infrastructure involved in delivering these hydrologic services has deeply altered the character of many river networks, with largely detrimental consequences for native species composition, nutrient cycling, and the form of banks, floodplains and deltas (World Commission on Dams (WCD), 2000; Brismar 2002; Bunn and Arthington 2002; Nilsson et al., 2005; Naiman and Dudgeon, 2010). These changes have weakened or excluded the production of naturally generated services, sometimes irreversibly.

The ecosystem service paradigm provides a cogent conceptual background within which to represent these tradeoffs and extend applied decision support analyses beyond the traditional

* Corresponding author.
E-mail address: da373@cornell.edu (D. A. Auerbach).
[1] Present address: Department of Ecology and Evolutionary Biology, Cornell University, Ithaca, NY, USA.
[2] Present address: Analysis Group, Inc. Economic, Financial, and Strategy Consulting, Menlo Park, CA, USA.
[3] Present address: Department of Biology, Bowling Green State University, Bowling Green, OH, USA.

http://dx.doi.org/10.1016/j.ecoser.2014.07.005
2212-0416/

Table 1
Likely effects of water infrastructure such as dams, levees, canals on ecosystem service values. In both developed and developing economies, many current policy and management decisions are based on well-recognized benefits derived from off-channel use of diverted surface water and in-channel use of water for industrial activities. Yet decisions to maximize benefits from these services tend to impose tradeoffs against services that are generated in the absence of significantly altered regimes of flow, sediment, temperature and nutrients. Quantified production and benefit functions as well as safe minimum standards for these "free-flowing" ecosystem services remain a research need, especially relative to the established methods and knowledge concerning services that depend on extensive infrastructure. See Wilson and Carpenter (1999), National Research Council (NRC) (2004), Brauman et al. (2007), and Korsgaard and Schou (2010) for further examples and citations.

Ecosystem service	Δ	Primary beneficiaries	Notes and examples
Diverted water for agricultural, municipal, industrial, and extractive energy use	+	Individuals, firms	Diversion may involve major in-channel structures and reservoir storage, off-channel conveyance and storage, or "as available" use requiring minimal construction within the river corridor.
Hydropower generation and thermoelectric cooling	+	Firms, states	Historically, these services have been fundamental to industrial economic development worldwide.
Transportation of people and materials	+/−	Individuals, firms, states	Industrialization has increased shipped volumes via dredging and channel reconfiguration, but realization of these services pre-dates heavy infrastructure interventions. Traditional use and access to rivers for transport may depend on flow and sediment regimes that dams alter.
Recreation and esthetic appreciation	−/+	Individuals	Reservoirs and flow regulation by dams may create new opportunities for boating and non-native sport fishing. They may simultaneously diminish benefits from non-motorized boating, native sport fishing, and wildlife viewing in the river corridor. Similarly mixed effects may occur for residential and commercial property values near channels and former channels. Likewise, major infrastructure projects may be regarded as a source of cultural pride or devastation.
Food and fiber from the river corridor	−/+	Individuals	Dams and levees tend to disfavor traditional and commercial in-channel harvests by disrupting reproductive cues and migrations, by disconnecting spawning habitats, and by facilitating populations of harmful non-native aquatic species. Similarly, major infrastructure may impair historically sustainable floodplain agriculture by ending periodic flushing and renewal of soil fertility.
Insurance from water-related catastrophes	−/+	Individuals, firms, states	Reservoirs may be operated with flood control objectives, but may also result in inadvertent bank stabilization and channel incision that increase flow velocity and hinder natural energy dissipation during high flows, thereby increasing the severity of large floods. Trapping of sediment in reservoirs, particularly in river systems with multiple dam sequences, may also lead to erosion of delta landforms, potentially rendering coastal population centers vulnerable to greater storm damage.
Preservation of native biodiversity	−/+	Individuals	Infrastructure that substantially contributes to species extinctions imposes an irreversible loss of natural heritage (a cost in terms of existence value) and sacrifices future enjoyment for the sake of present desires (a cost in terms of bequest value). However, in heavily managed river systems, unanticipated opportunities may arise to operate infrastructure in ways that favor threatened biota (e.g., intentional flooding to stimulate reproduction). In general, the intergenerational legacy of infrastructure is a complex mix of ongoing capital and maintenance costs, restoration costs following decommissioning, and opportunity costs under changing social and environmental conditions.
Pollutant removal and disease transmission risk	**?**	Individuals, states	Infrastructure that slows water velocity and impairs riparian ecosystem function creates the potential for concentrated contaminant "hotspots" of inorganic pollutants that require expensive, difficult remediation. In addition, dams and levees may harm species such as freshwater mussels that naturally regulate water quality. Reservoirs may raise the risk of undesirable eutrophication, but additional research is warranted regarding the consequences of infrastructure for the processing of nitrogen, phosphorous and other organic compounds as well as for the conveyance of water-borne pathogens or the abundance of disease hosts.

emphases of water resource management. Ecosystem service assessments may effectively capture the opportunity cost of benefits lost with infrastructure construction and may highlight the benefits of river restoration and future decommissioning costs. Nonetheless, routinely conducting such assessments will require researchers and practitioners to overcome two basic and related challenges: the set of ecosystem services produced under free-flowing conditions must first be recognized, and these "free-flowing services" must then be consistently integrated into assessments.

2. Recognizing the benefits of free-flowing rivers

Ecosystem service assessments have an important role to play in raising awareness of the benefits of free-flowing rivers among decision makers, particularly in wealthy nations where dams, diversions, levees, locks, and related water infrastructure are now so prevalent as to be largely societally ingrained. We describe several examples in this section, and Table 1 compiles changes likely to follow construction of extensive hard infrastructure, drawing from comprehensive treatments of ecosystem services directly related to surface water quantity, quality and timing (Wilson and Carpenter 1999; NRC, 2004; Brauman et al., 2007; Korsgaard and Schou, 2010).

Fisheries and recreational enjoyment of rivers are prominent among the benefits that may decline with the intensification of hard infrastructure. Though novel recreation may arise on reservoirs or in their tailwaters (e.g., angling for introduced fish species), recreational activities such as rafting or wildlife viewing can suffer with dam construction, and numerous studies have described the detrimental effect of dams on fish-related services (Holmlund and Hammer, 1999). Important commercial and subsistence stocks of both freshwater and diadromous species, such as salmon, may suffer as a result of habitat fragmentation and loss, introduction of competitors and predators, and the elimination of spawning cues. For example, Hoeinghaus et al. (2009) found that populations of native, high-value species declined after impoundment of the Paraná River (Brazil), and that annual total yield decreased from more than 1500 to less than 1000 t despite an increase of effort from less than 70,000 to more than 120,000 fishing days. Conversely, Butler et al. (2009) found significant local economic benefits from recreational fisheries associated with the minimally altered River Spey (Scotland), reporting that aggregate