Restoring Rivers and Streams

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Article Contents

Increasingly, management agencies are attempting to reverse degradation to rivers through ecosystem restoration, whereby efforts are made to remediate, improve or return degraded rivers back to their historic form and function. River restoration has become a booming industry throughout the developed world, with a wide variety of methods currently employed. Common activities include: reshaping channels back to historic or reference dimensions, planting riparian vegetation, and constructing high-quality habitat for fish. The goals driving these restoration projects are also diverse, ranging from improving water quality to achieving improved aesthetic and recreational benefits. Restoration efforts may improve local conditions by reducing bank erosion, reducing stream temperatures and increasing dissolved oxygen concentrations, but to date there has been little empirical evidence for catchment-scale improvements in water quality, aquatic biodiversity, or recovery of sensitive aquatic taxa.

The Need to Restore River Ecosystems

Increasingly, environmental sciences must focus on ecosystems which have been fundamentally altered by human activity (Palmer *et al.*, 2004). As we acknowledge that it is insufficient to study the few remaining pockets of wilderness, new research must examine whether and how to restore ecosystems to previous states of physical and ecological health or function (Dobson *et al.*, 1997). Restoration is inherently a multidisciplinary enterprise, requiring expertise from numerous natural and social science disciplines, such as ecology, biology, engineering, geography, anthropology and landscape architecture (NRC, 1996; Zedler, 2000). Yet integrating diverse theories, research methods and different viewpoints on the objectives of effective restoration is an enormous challenge (Benda *et al.*, 2002; Poff *et al.*, 2003; Palmer *et al.*, 2005). **See also**: Bioremediation; Restoration and Creation of Freshwater and Estuarine Wetlands

Concern over the impacts that land use changes may have on the ability of river systems to provide the ecological and social services upon which human life depends has resulted in the initiation of major investments in river restoration (Postel and Richter, 2003). Indeed, river and stream restoration has become a worldwide phenomenon as well as a booming enterprise (e.g. Bernhardt *et al.*, 2005; Zedler, 2000). In parts of the world there is already insufficient water to supply basic human needs and even when it is available, it is often not clean enough for drinking and agriculture (Baron *et al.*, 2002; Vorosmarty, 2002). More than one-third of the rivers in the U.S. are officially listed as impaired or polluted (EPA, 2000), and many U.S. rivers carry pollutant loads to coastal zones that contribute to the decline of coastal fisheries and recreational areas (Rabalais *et al.*, 2002; Beman *et al.*, 2005). Freshwater biota have been heavily impacted by changes in land use. In North America alone, 34% of freshwater fish are 'red listed' as extinct, threatened or vulnerable (Sand-Jensen, 2000). In Europe, habitat degradation, water pollution and water shortage are all threatening the integrity of aquatic ecosystems and societies that depend on them (Nijland and Cals, 2001). Throughout the developing world, freshwaters may be even more threatened, for example, many of the rivers in China are now classified as too polluted to sustain fisheries (Dudgeon, 2005). Indeed, the risk of future extinction for freshwater biota globally is projected to be five times higher than that for terrestrial biota and even two times higher than that for coastal mammals (Ricciardi and Rasmussen, 1999). **See also**: Biogeochemical Cycles

Although technological solutions will certainly play a role in the future of our water resources, ecological restoration of streams and rivers is increasingly recognized as critical to a sustainable future (NRC, 1996; Postel and Richter, 2003). Ecological restoration is being coupled with conservation and environmental mitigation to help manage human-dominated ecosystems (SER, 2002; Palmer *et al.*, 2004). Successful ecological restoration of rivers should result in a watershed's improved capacity to provide

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important ecosystem goods and services such as drinkable water and consumable fish (Palmer *et al*., 2005).

Over the past two decades, the importance of ecological restoration has grown dramatically leading to the formation of a professional society and a related increase in scientific studies, greatly increased availability of funds for restoration action, and an expanding pool of restoration consultants and practitioners. Restoration of aquatic ecosystems has been in the vanguard, and is perhaps best-known to the public through high-profile efforts in the Everglades and the Grand Canyon in the U.S. (NRC, 2006; Cohn, 2001), projects on the Rhine and Danube Rivers in Europe (Buijse *et al*., 2002) and massive efforts to mitigate for aquatic ecosystem damage resulting for the Three Gorges damn in China (Stone, 2008). In other developing countries restoration and rehabilitation of streams are also increasing in response in declining fish populations, increased frequency of flooding and lack of enough stream discharge to meet all demands (Parish, 2004). The value of ecological restoration of streams and rivers is now widely accepted (NRC, 1996; Postel and Richter, 2003; Palmer *et al*., 2004), promising an improved capacity to provide clean water, consumable fish, wildlife habitat and healthier coastal waters.

What Is River Restoration?

Currently, there are many definitions for restoration of freshwater ecosystems, ranging from the idealistic: 'The complete structural and functional return to a predisturbance state' (Cairns, 1991); to the more pragmatic: 'The act of restoration to an improved or former condition' (Sear, 1994) or, in cases where historic conditions cannot be recovered, 'The birth of a new (alternative) ecosystem that previously did not exist at the site' (NRC, 1992). The Society for Restoration Ecology defines restoration as 'the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed' (SER, 2002). Terms like rehabilitation ('The act of restoration to an improved or former condition' (Sear, 1994)) and enhancement ('Any improvement of a structural or functional attribute' (NRC, 1992)) are frequently used as synonyms for restoration. In practice, the term 'river restoration' has been used as a catch all term for a variety of river management activities including restoration, rehabilitation, enhancement and/or creation (Bernhardt *et al*., 2007).

The most commonly cited reasons for restoration in the U.S. are to enhance water quality, to manage riparian zones, to improve in-stream habitat, for fish passage and for bank stabilization (Bernhardt *et al*., 2005). Riparian management and water quality were also the main goals for river restoration in Victoria, Australia (Brooks and Lake, 2007). In Europe, changing environmental, economic and social preferences are fuelling an increase in integrated river restoration approaches (Nijland and Cals, 2001). In China there are large efforts underway to restore floodplain forests and wetlands to reduce flooding around the Yangtze River, in addition to smaller local restoration projects seeking to ensure water supplies for small communities (Tullos, 2006).

Stream and river restoration projects are implemented daily, making river restoration a booming, highly profitable business (NRC, 1999; Anonymous, 2002; Henry *et al*., 2002; Carpenter *et al*., 2004; Malakoff, 2004). Unlike wetland restoration, only a small percentage of river restoration projects are compensatory mitigation projects (Bernhardt *et al*., 2007). The number of restoration projects has increased exponentially in the last decade, as evidenced by increases in popular and scientific articles on the subject (**Figure 1**). The majority of these popular and scientific articles come from North America and Europe. A recent review of the global literature found 345 scientific articles assessing the effectiveness of river restoration, with only 21 studies from outside the U.S., Canada and Europe (Roni *et al*., 2008). It is estimated that in the U.S., an average of more than $1 billon USD are spent annually on stream and river restoration (Bernhardt *et al*., 2005). This estimate does not reflect the full cost of large-scale restoration projects such as the Kissimmee River, San Francisco Bay, Columbia and Missouri rivers, which would add hundred of millions to billions of dollars (Bernhardt *et al*., 2005). Perhaps the largest restoration project of freshwater ecosystems in the U.S. is the Comprehensive Everglades Restoration Project with a 40-year plan and a $20 billion budget (NRC, 2006). Relatively few projects are conducted at such a large scale (time, area and budget), in the U.S. the majority of projects are small in scope (< 1 km of stream length) and have a median cost of < $45 000. In southern Australia, the dominant restoration activity is riparian management, with approximately U.S. $30 million spent per year from 1999 to 2001 (Brooks and Lake, 2007).

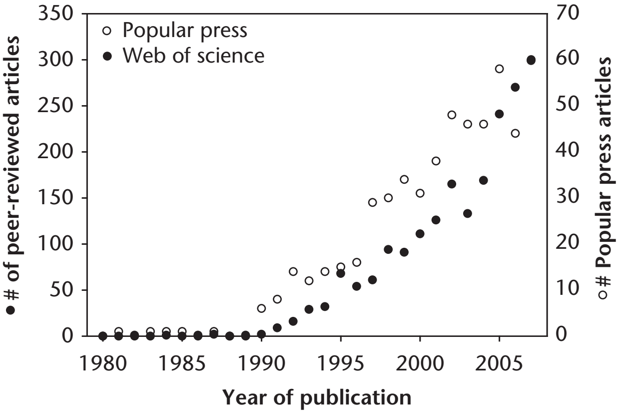


Figure 1 Number of peer-reviewed articles (black circles) and popular press articles (white circles) related to river restoration. Citations were derived from a search for 'stream restoration' or 'river restoration' in ISI Web of Science and Lexis Nexis Environmental News. Modified from Bernhardt *et al.* (2005). Reproduced by permission of AAAS.

How Is Restoration Done?

The range of common practices currently considered to fall under the term restoration reflects the diversity in stakeholder concerns, scientific training, spatial scales of interest and local environmental constraints (**Table 1**). These practices range from 'quick fixes' at the reach scale, such as bank stabilization, reforestation of riparian areas, engineering fish habitat, to more ambitious and long-term manipulations of river-basin-scale ecosystem processes and biota (**Figure 2**; **Box 1** and **Box 2**; Wohl *et al*., 2005). Typically many of these practices are undertaken simultaneously within an individual restoration project (Roni *et al*., 2008). For example, channel reconfiguration, which consists of altering the longitudinal profile of a stream and remeandering the channel, is commonly implemented along with structures that stabilize banks, lead to floodplain reconnection and increase the amount and quality of riparian vegetation (**Table 1**).

Increasing the lateral and longitudinal connectivity of river ecosystems is also a common goal of restoration practices. Increasing lateral connectivity through floodplain reconnection, which seeks to promote the exchange of organisms and materials between riverine and floodplain areas, has been a major goal of the large restoration efforts in the Kissimmee River (**Table 1**; **Box 1**). Floodplain reconnection is commonly achieved by removal of levies, remeandering of channels and creation of connected ponds and channels (Roni *et al*., 2008). Increasing longitudinal connection along the river is usually achieved through dam removal or dam retrofitting for fish passage to allow the upstream/downstream migration of fishes (**Table 1**; **Box 2**). In the absence of dam removal, restoration of natural flow regimes has been proposed as a method to restore or improve processes such as sediment transport and regeneration of riparian vegetation (Stromberg, 2001; Poff *et al*., 2003). A notable test of this technique has been in the U.S. Grand Canyon, where high flow events have led to changes in riparian colonization and removal of woody vegetation that had colonized due to flow control (Stromberg, 2001).

The Natural Channel Design (NCD) approach (Rosgen, 1994, 1996) is widely used to guide stream restoration throughout the U.S. and Europe (**Box 3**). This approach provides guidance for physically reshaping and stabilizing degraded stream channels to obtain the pattern and profile of either the historic condition of a stream channel or a channel that approximates the reference conditions for the same watershed (Rosgen, 1994). One of the largest such NCD restoration projects took place in the Netherlands (Pedersen *et al*., 2007). Between 1999 and 2002, 19 km of

Table 1 Common river restoration practices

Aesthetics/recreation/education: Activities that increase the community value for river ecosystems: use, appearance, access, safety and knowledge

Bank stabilization: Practices designed to reduce/eliminate erosion or slumping of bank material into the river channel

Channel reconfiguration: Alteration of channel plan form or longitudinal profile and/or daylighting (converting culverts and pipes to open channels). Includes stream meander restoration and in-channel structures that alter the thalweg of the stream

Dam removal/retrofit: Removal of dams and weirs or modifications/retrofits in existing dams to reduce negative ecological impacts

Fish passage: Removal of barriers to upstream/downstream migration of fishes. Includes the physical removal of barriers and also construction of alternative pathways. Includes migration barriers placed at strategic locations along streams to prevent undesirable species from accessing upstream areas

Floodplain reconnection: Practices that increase the flood frequency of floodplain areas or that promote exchanges of organisms and materials between riverine and floodplain areas

Flow modification: Practices that alter the timing and delivery of water quantity. Typically, but not necessarily associated with releases from impoundments and constructed flow regulators

In-stream habitat improvement: Altering structural complexity to increase habitat availability and diversity for target organisms and provision of breeding habitat and refugia from disturbance and predation

In-stream species management: Practices that directly alter aquatic native species distribution and abundance through the addition (stocking) or translocation of animal and plant species and/or removal of exotics

Land acquisition: Practices that obtain lease/title/easements for streamside land for the explicit purpose of preservation or removal of impacting agents and/or to facilitate future restoration projects

Riparian management: Revegetation of riparian zone and/or removal of exotic species (e.g. weeds and cattle)

Stormwater management: Special case of flow modification that includes the construction and management of structures (ponds, wetlands and flow regulators) in urban areas to modify the release of storm run-off into waterways from watersheds with elevated imperviousness into waterways. These practices/structures generally aim to reduce peak flow magnitudes and extend flow duration

Water quality management: Practices that protect existing water quality or change the chemical composition and/or suspended particulate load. Remediation of acid mine drainage falls into this category, as does Combined Sewer Overflow separation. Excludes urban run-off quantity management (see Stormwater Management)

Sources: Adapted from the National Riverine Restoration Science Synthesis, Bernhardt *et al*. (2007). Reproduced by permission of Wiley-Blackwell.

Figure 2 Photographs of common restoration practices: (a) an urban 'daylighting' project in which a formerly piped stream is uncovered; (b) installation of a natural channel design project; (c) a rock weir structure installed for grade control within a natural channel design project; (d) removal of invasive species from riparian areas; (e) improved, large diameter road culverts installed to allow fish passage and (f) bank stabilization with root wads and coir fibre matting. Photo credits: (a) Chris Benton, (b) Barbara Doll, (c) Emily Bernhardt, (d) Jennifer Follstad Shah, (e) Marcelo Ardón and (f) Emily Bernhardt.

the Skjern River, the largest river in Denmark, and 22 km^2 of its valley were restored into a meandering river with wetlands, meadows and shallow lakes within its floodplain. Monitoring of this system has shown improvements in habitat complexity and channel morphology followed by rapid colonization of the restored river and floodplains by plants and invertebrates from upstream reaches (Pedersen *et al*., 2007).

Current policies and restoration practitioners tend to focus on changes to the physical structure of streams, mostly as a result of the important historical role of hydrologists and hydraulic engineers in river and stream management (Palmer and Bernhardt, 2006). This focus on the channel structure comes from an early emphasis on flood control and the desire to efficiently move water out of the landscape. The basic assumption behind this emphasis on physical structure has been called as the 'field of dreams' myth of ecological restoration – that is, restoration projects often assume that 'if we build it, they will come', with 'they' referring to a suite of species and ecosystem functions that occur in reference streams (Hilderbrand *et al*., 2005). Ecologists, biologists and geomorphologists are becoming increasingly involved in river restoration research, and are attempting to expand the focus from rivers as channels to rivers as natural, living systems (Palmer *et al*., 2005; Wohl *et al*., 2005). These disciplinary perspectives are pointing out that projects should focus on restoring the underlying processes that sustain species and ecosystem function as well as restoring structure and form (Palmer and Bernhardt, 2006). For example, channel reconfiguration to reduce erosion often fails due to the lack of riparian vegetation to provide physical stability to the channel. If the recruitment of riparian vegetation is not restored (by ensuring that seed dispersal and germination occur) native vegetation is unlikely to get established, and even if planted may not survive (Palmer and Bernhardt, 2006). Similarly, channel reconfiguration projects conducted to reduce sediment transport may fail unless in-channel efforts are associated with watershed-scale efforts to reduce peak storm flows (Smith and Prestegaard, 2005; Kondolf, 2006; **Box 3**). Another common myth in restoration is the 'fast forwarding', suggesting that we can jump start ecosystem development by controlling dispersal, colonization and community assemblage (Hilderbrand *et al*., 2005). Many restoration projects rely on plantings to speed up the desired ecosystem trajectory and recovery; however, there is little evidence that it is possible to achieve the desired ecosystem state or function in the shortened time spans (Hilderbrand *et al*., 2005). Associated with this problem is the 'cookbook' myth, the idea that because an approach is successful in one place it can be generalized and applied everywhere (Hilderbrand *et al*., 2005).

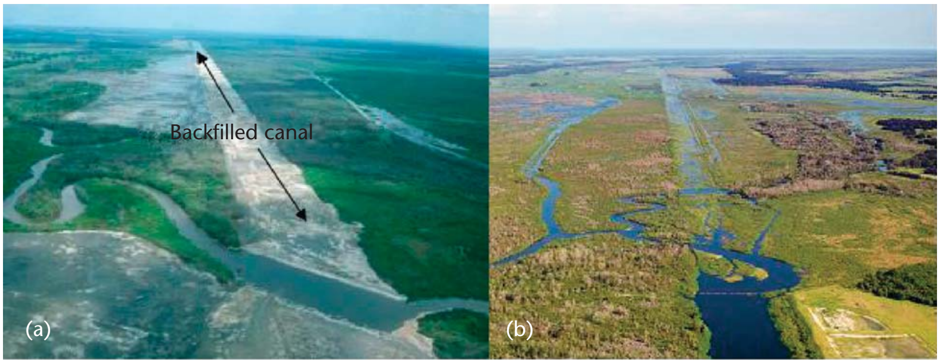
Kondolf *et al*. (2006) proposed four tasks for implementing ecologically effective restoration projects: (1) assess historical conditions within a river; (2) develop a clear definition of 'ecological degradation' in terms of changes in ecosystem processes; (3) identify human activities that have led to degradation and (4) agree on which ecological processes are most important for restoration and how much ecological restoration should be incorporated into the overall goal of the project. Kondolf *et al*. (2006) emphasize the importance of incorporating knowledge of hydrologic connectivity and flow dynamics into restoration plans. Hydrologic connectivity is defined as 'water-mediated transfer of matter, energy and organisms within or between elements of the hydrologic cycle' (Pringle, 2001). Humans tend to alter longitudinal, lateral and vertical connectivity and changes in flow dynamics of streams, but historically restoration efforts have focused on restoring hydrologic connections but not flow dynamics – thus missing a critical component of hydrologic connectivity. It is important that restoration projects are designed

Box 1 Kissimmee River Restoration project

The Kissimmee River is an example of a large-scale restoration project with clearly defined goals, measures of success and complete documentation from its inception (Bousquin *et al*., 2008). Channelization of the Kissimmee River occurred between 1962 and 1971, transformed 167 km of river into a large drainage canal with levees and water control structures (Whalen *et al*., 2002). Whereas the channelization was successful in controlling floods, it had negative effects on the ecosystem. Channelization drained 21 000 ha of floodplain wetlands and severely impacted fish and other wildlife populations (Whalen *et al*., 2002). A joint effort by the South Florida Water Management District and the U.S. Army Corp of Engineers now seeks to restore 'ecological integrity' to a contiguous area of floodplain and river of over 39 mile^2 (109 km^2; Bousquin *et al*., 2008). New wetlands will reestablish in more than 20 mile^2 (51 km^2) that were drained by the canal, and 40 miles (70 km) of the river channel will be hydrologically reconnected (Bousquin *et al*., 2008).

The 620 million dollar restoration project seeks to reestablish 'ecological integrity' by reconstructing the natural channel and reestablishing the natural hydrologic regime (Bousquin *et al*., 2009). 'Ecological integrity' was defined as 'reestablishment of a river/floodplain ecosystem that is capable of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of a natural habitat of the region' (Whalen *et al*., 2002). Based on this overarching goal, 25 expectations have been established to monitor the ecosystem's recovery (Bousquin *et al*., 2008). In the first two phases of restoration, which were completed in 2007, 10 miles (16.1 km) of canal were backfilled, 2 miles (3.2 km) of river channel were recarved and more than 6000 acres (2400 ha) of wetlands were gained (Bousquin *et al*., 2009). In the last two phases, projected for completion by 2013, more than 12 miles (19.3 km) of the canal will be backfilled, 8 miles (12.8 km) of river channel will be recarved and more than 6000 acres (2400 ha) of wetlands will be gained (Bousquin *et al*., 2009).

Photos for Box 1. The Kissimmee River restoration project. Much of the Kissmmee River was channelized and was routed via canal between 1962 and 1971. The Kissmmee River restoration project is restoring flow to the historic channel by backfilling the canal and removing flow obstructions as seen in this 2001 photos (a); leading to a reconnected floodplain and wetlands as seen in this 2005 photos (b). Photo credits: Stephen G. Bousquin, South Florida Water Management District.



to reverse multiple insults rather than focusing on a single aspect of degradation (Kondolf *et al*., 2006).

What Does Success Mean and How Is It Being Evaluated?

Restoration success can be evaluated from a range of perspectives ranging from benefits to public education to improving ecological conditions. European restoration efforts seek to meet the technological and ecological challenges while raising public awareness and support for these kinds of projects (Buijse *et al*., 2002). To date there are no agreed standards for what constitutes an ecologically successful restoration project. Palmer *et al*. (2005) suggested five criteria for measuring success from an ecological perspective. First, the design of an ecological river and/or stream restoration project should be based on an image of a more dynamic, healthy river that could exist at the site. Second, the river's ecological condition must improve in ecological parameters that can be quantified. Third, the restored river system must be more self-sustaining and resilient to external perturbations, so that minimal maintenance is required. Fourth, during construction no lasting harm should be inflicted on the ecosystem. Fifth, both pre- and postassessment must be completed and data must be available to the public. Without clearly defined criteria

Box 2 Removal of Carbonton Dam, North Carolina

As dam's in the U.S. age beyond their intended design lives (Doyle *et al*., 2008), some states are providing incentives to remove dams as means of river restoration. Whereas dam removal provides positive impacts on rivers, there are also negative aspects such as increased nutrient and sediments loads to downstream ecosystems (Stanley and Doyle, 2002). Increased sediment loads can affect aquatic invertebrates and fish, and nutrient loading can impair receiving waters (Riggsbee *et al*., 2007). To reduce sediment loading and nutrient loading to downstream ecosystems, dam removal is usually carried out in three stages: dewatering, breaching and complete removal.

The Carbonton Dam was located on the Deep River in the piedmont region of North Carolina. The dam was removed in December 2005 to restore natural, free-flowing regime to the Deep River. The dam was removed as part of a mitigation programme, in which credits for habitat creation were sold to compensate for impacts elsewhere (Doyle *et al*., 2008). Removal of the dam resulted in rapid recovery of the federally listed endangered Cape Fear shiner (*Notropis mekistocholas*), which was found upstream from the former dam in less than 2 years after removal.

Photos for Box 2. Photographs of the removal of Carbonton Dam, North Carolina.
Photos cretits: Adam Riggsbee.

Box 3 Cuneo Creek channel reconfiguration

Cuneo Creek drains 10.8 km^2 of the Coast Ranges in California. The climate in this area is Mediterranean with highly seasonal winter rainfall, high interannual variability in precipitation and an episodic flow regime (Kondolf, 2006). Owing to deforestation in the early 1950s and 1960s, massive hill slope erosion lead to large sediment loads in Cuneo Creek. In the 1960s, the California Department of Parks and Recreation bought the deforested Cuneo Creek catchment to restore and reduce the sediment load to downstream systems (Kondolf, 2006). In 1991, a 520-m reach of Cuneo Creek was restored guided by a general classification system. In 1997, the constructed channel washed out after a 30-year flood. Before restoration the Cuneo Creek channel was braided, with multiple threads shifting over an active channel bed of gravel and sand. The pre-project braided channel reflected its high sediment load and the episodic flow regime characteristic of the Mediterranean climate. Without reducing the supply of sediments coming from hill slopes and changing the episodic hydrology it is unclear how constructing a narrow, single-thread, meandering channel could be expected to change Cuneo Creek in the long term (Kondolf, 2006).

supported by funding and implementing agencies, there is little incentive for practitioners to assess and report restoration outcomes (Palmer *et al*., 2005).

A global review of the literature of the biological effectiveness of river restoration techniques found that despite 345 published studies, it is still too early to draw firm conclusions due to the short-term duration and limited scope of most studies (Roni *et al*., 2008). The outcomes of most of the tens and thousands of small to medium projects in the U.S. are currently not being adequately tracked (Bernhardt *et al*., 2005). A comprehensive assessment of restoration progress in the U.S. is currently not possible with the 'piecemeal' information available (Bernhardt *et al*., 2005, 2007). Only 10% of approximately 37 000 projects surveyed in the U.S. indicate any kind of monitoring (Bernhardt *et al*., 2005). Whereas different steps of the restoration process require monitoring, there is little incentive for post-project restoration of ecological parameters (Palmer *et al*., 2005). Monitoring might be required to obtain permits (permit monitoring), implementation monitoring is done to determine if structures or forms are serving their desired function, and outcome monitoring is done to determine whether success criteria are being accomplished. Project managers report that while ecological degradation typically motivated restoration projects, post-project appearance and positive public opinion were the most commonly used metrics of success (Bernhardt *et al*., 2007).

It is important to include biological, chemical and physical data in post-project monitoring plans (Palmer *et al*., 2005; Roni *et al*., 2008), yet only very few projects included a combination of all three parameters. Photographic and visual monitoring was also a part of many project-monitoring programmes. A majority of these projects indicated that they conducted both pre- and postconstructions, and almost 30% included monitoring of a nearby reference site (Bernhardt *et al*., 2007). Practitioners often cite lack of funding and time as the main reasons why post-project monitoring is not routinely incorporated into restoration projects.

Improving the Practice – What Needs to Change?

Determining 'success' in a restoration context is difficult, as restoration outcomes could be viewed from many perspectives: Was the project accomplished cost-effectively? Were the stakeholders satisfied with the outcome? Was the project aesthetically pleasing? Yet, projects that do not improve the ability of rivers to provide the goods and services upon which life depends: clean water for human consumption and agriculture, fisheries for food and livelihood, and diverse biota critical to ecosystem functions (Baron *et al*., 2002; Postel and Richter, 2003) cannot be called as ecological successes. Thus, the restoration of *ecological* communities and biogeochemical function is of prime importance in the restoration of running waters (Palmer *et al*., 2005).

To improve the environmental conditions for the highest possible number of degraded stream miles, river restoration scientists, practitioners and water resources managers should strive to increase the ecological and cost effectiveness of restoration strategies. As the practice of river restoration continues to expand, the need to develop a sound scientific basis is critical. A number of working groups and policy initiatives in the U.S. have focused on this topic in government (United States Geological Survey (USGS) interagency River Science Network), environmental organizations (Nature Conservancy, American Rivers) and academia (National Riverine Restoration Science Synthesis and the National Center for Earth-Surface Dynamics). Similar efforts are being conducted in Europe (Nijland and Cals, 2001), Australia (Brooks and Lake, 2007) and China (Tullos, 2006). Some common suggestions on how to improve the practice of river restoration:

- Restoration projects need to shift their focus towards rivers that provide multiple ecosystem functions instead of overemphasizing channel form and pattern (Wohl *et al*., 2005; Kondolf *et al*., 2006).
- Recognize limits to our knowledge of historic conditions and impacts when identifying restoration goals. Seek to incorporate a solid understanding of current and future land use and climate impacts (Wohl *et al*., 2005; Bernhardt and Palmer, 2007; Walter and Merritts, 2008).
- Restoration practitioners and scientists as well as watershed managers need to move beyond the dichotomy of success versus failure in restoration evaluation, and instead begin to gauge the relative effectiveness of diverse restoration strategies (Bernhardt *et al*., 2007).
- Ultimately, restoration goals need to be realistic. It is not possible to mitigate all catchment insults through reach-scale river restoration projects. Thus river restoration efforts need to be integrated with best management practices and intelligent land use planning at the catchment scale (Bernhardt and Palmer, 2007; Craig *et al*., 2008).

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