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FORUM

Standards for ecologically successful river restoration

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Summary

1. Increasingly, river managers are turning from hard engineering solutions to ecologically based restoration activities in order to improve degraded waterways. River restoration projects aim to maintain or increase ecosystem goods and services while protecting downstream and coastal ecosystems. There is growing interest in applying river restoration techniques to solve environmental problems, yet little agreement exists on what constitutes a successful river restoration effort.

2. We propose five criteria for measuring success, with emphasis on an ecological perspective. First, the design of an ecological river restoration project should be based on a specified guiding image of a more dynamic, healthy river that could exist at the site. Secondly, the river's ecological condition must be measurably improved. Thirdly, the river system must be more self-sustaining and resilient to external perturbations so that only minimal follow-up maintenance is needed. Fourthly, during the construction phase, no lasting harm should be inflicted on the ecosystem. Fifthly, both pre- and post-assessment must be completed and data made publicly available.

3. Determining if these five criteria have been met for a particular project requires development of an assessment protocol. We suggest standards of evaluation for each of the five criteria and provide examples of suitable indicators.

4. *Synthesis and applications.* Billions of dollars are currently spent restoring streams and rivers, yet to date there are no agreed upon standards for what constitutes ecologically beneficial stream and river restoration. We propose five criteria that must be met for a river restoration project to be considered ecologically successful. It is critical that the broad restoration community, including funding agencies, practitioners and citizen restoration groups, adopt criteria for defining and assessing ecological success in restoration. Standards are needed because progress in the science and practice of river restoration has been hampered by the lack of agreed upon criteria for judging ecological success. Without well-accepted criteria that are ultimately supported by funding and implementing agencies, there is little incentive for practitioners to assess and report restoration outcomes. Improving methods and weighing the ecological benefits of various restoration approaches require organized national-level reporting systems.

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Introduction

Healthy, self-sustaining river systems provide important ecological and social goods and services upon which human life depends (Postel & Richter 2003). Concern over sustaining these services has stimulated major restoration efforts. Indeed, river and stream restoration has become a world-wide phenomenon as well as a booming enterprise (NRC 1996; Holmes 1998; Henry, Amoros & Roset 2002; Ormerod 2003). Billions of dollars are being spent on stream and river restoration in the USA alone (Palmer *et al.* 2003; Malakoff 2004). Although there is growing consensus about the importance of river restoration, agreement on what constitutes a successful restoration project continues to be lacking. Given the rapid rate of global degradation of freshwaters (Gleick 2003), it is time to agree on what constitutes successful river and stream restoration.

We propose five criteria for measuring success, hereafter referred to as the standards for ecologically successful river restoration. We chose a forum to propose these in order to elicit broad input from the community, including critiques and suggestions for expanding or revising what we propose. It is our hope that, after debate and careful consideration, the international scientific community can reach consensus on a set of standards. The next step would involve seeking approval of the standards by the practitioner community and a diverse array of scientific societies (e.g. ecological, water, and restoration societies of various countries) and receiving eventual endorsement from the United Nations Environmental Programme. The Comment papers by Gillilan *et al.* (2005) and Jansson *et al.* (2005) in this issue are encouraging and provide the kind of feedback needed to advance the debate. Much thought has been put into evaluating restoration and there is already a rich literature (NRC 1992; Kondolf & Micheli 1995; Kauffman *et al.* 1997). Drawing on this valuable body of work and our recent experiences in establishing comprehensive river restoration databases for the USA and Australia (Palmer *et al.* 2003; www.nrrss.umd.edu), we identify elements that we consider essential to achieving ecological success. Once a general agreement on reasonable success criteria has been reached, indicators to evaluate ecologically successful restoration must be identified.

Why the need for ecological standards?

The success of a restoration project could be evaluated in many different ways. Was the project accomplished cost-effectively? Were the stakeholders satisfied with the outcome? Was the final product aesthetically pleasing? Did the project protect important infrastructure near the river? Did the project result in increased recreational opportunities and community education about rivers? Did the project advance the state of restoration science? However, for the following reasons, we argue that projects initiated in whole or in part to restore a river or stream must also be judged on whether the restoration is an ecological success.

First, many projects are funded and implemented in the name of restoration, with the implication that improving environmental conditions is the primary aim. Protecting infrastructure and creating parks are important activities but do not constitute ecological restoration and many in fact actually degrade nearby waterways. For example, riverfront revitalization projects may be successful in increasing economic and social activity near a river but can constrain natural processes of the river and floodplain (Johansson & Nilsson 2002). Similarly, channel reconfiguration from a braided to a single-thread morphology may be aesthetically pleasing but inappropriate for local geomorphic conditions (Kondolf, Smeltzer & Railsback 2001). Thus, projects labelled restoration successes should not be assumed to be ecological successes. While other objectives have value in their own right, river restoration connotes 'ecological' and should be distinguished from other types of improvement. In the ideal situation, projects that satisfy stakeholder needs and advance the science and practice of river restoration (learning success) could also be ecological successes (Fig. 1).

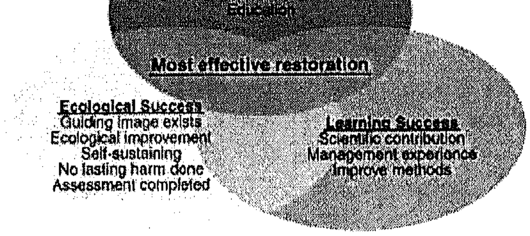

Fig. 1. The most effective river restoration projects lie at the intersection of the three primary axes of success. This study focuses on the five attributes of ecological success, but recognizes that overall restoration success has these additional axes. Stakeholder success reflects human satisfaction with restoration outcome, whereas learning success reflects advances in scientific knowledge and management practices that will benefit future restoration action.

Secondly, progress in the science and practice of river restoration has been hampered by the lack of agreed upon criteria for judging ecological success. Without well-accepted criteria that are ultimately supported by funding and implementing agencies, there is little incentive for practitioners to assess and report restoration outcomes. At present, information on most restoration efforts is largely inaccessible and, despite pleas to report long-term responses (Zedler 2000; Hansen 2001), most projects are never monitored post-restoration (NRC 1992). Our interest here is not which monitoring methods are employed, but rather which criteria are used to determine if a project is a success or failure ecologically. Bradshaw (1993), Hobbs & Norton (1996), Hobbs & Harris (2001), Lake (2001) and many others have long argued that restoration evaluation is crucial to the future of ecological restoration. This begs the question of evaluation with respect to what? What criteria can be brought to bear in evaluating success? While the objectives of ecosystem restoration are ultimately a social decision; if they are to include ecological improvement then we argue that the following criteria must be met.

Five criteria for ecological success

A GUIDING IMAGE EXISTS: A DYNAMIC ECOLOGICAL ENDPOINT IS IDENTIFIED A PRIORI AND USED TO GUIDE THE RESTORATION

Here we build upon the leitbild concept used to guide channel restoration efforts in Germany (Kern 1992, 1994). We propose that the first step in river restoration should be articulation of a guiding image that describes the dynamic, ecologically healthy river that could exist at a given site. This image may be influenced by irrevocable changes to catchment hydrology and geomorphology, by permanent infrastructure on the floodplain and banks, or by introduced non-native species that cannot be removed. Rather than attempt to recreate unachievable or even unknown historical conditions, we argue for a more pragmatic approach in which the restoration goal should be to move the river towards the least degraded and most ecologically dynamic state possible, given the regional context (Middleton 1999; Choi 2004; Palmer *et al.* 2004; Suding, Gross & Housman 2004).

Throughout, we use the term ecological in a very general sense to include biological, hydrological and geomorphic aspects of natural systems. Thus an ecologically dynamic state is one in which the biota vary in abundance and composition over time and space, as they do in appropriate reference systems, and the channel shape and configuration also change in response to the natural flow variability characteristic of the region. An ecologically dynamic state is also resilient to external perturbations. It is essential for practitioners to recognize that there can be no universally applicable restoration endpoint given the regional differences in geology, climate, vegetation, land-use history and species distribution.

Many approaches exist for establishing a guiding image for restoration efforts; these approaches are not mutually exclusive and are often complementary. First, historical information, such as aerial photographs, maps, ground photography and land and biological survey records can be used to establish prior conditions (Koebel 1995; Kondolf & Larson 1995; Toth *et al.* 1995). This can provide valuable insights into how the channel or biota may have changed. For example, application of US Government land office surveys from the early 1800s to describe floodplain forest vegetation in the pre- or early settlement lower Missouri (Bragg & Tatschl 1977) and upper Mississippi (Yin & Nelson 1996) rivers provided a reference against which to design and evaluate contemporary rehabilitation efforts (Galat *et al.* 1998; Sparks, Nelson & Yin 1998). Historical research does not imply an objective of recreating historical conditions, rather an attempt to account explicitly for historical changes because of natural and anthropogenic disturbances and to understand resource conditions that may have been lost and irreversible changes that may have occurred (Pedroli *et al.* 2002).

Secondly, relatively undisturbed or already recovered reference sites can be used to help frame restoration goals (Rheinhardt *et al.* 1999), particularly where historical information is lacking. These are, in effect, space-for-time substitutions, with the reference sites assumed to represent less disturbed channel conditions and biological assemblage composition. In selecting analogue sites, inherent differences among locations in geology, climate, position in the catchment, fluvial geomorphology, hydrology and zoogeography must be considered. For example, if all reference sites are in steeper upstream reaches because all the lowland reaches have been affected by land-use change, their value to guide restoration of the lowland channels will be limited. Similarly, understanding the historical context of fish species distribution is necessary to understand which species might reasonably be expected in a given drainage basin (Strange 1999). Finding reference sites for large rivers is particularly problematic. In some cases, it may make sense to use a heavily impaired river as a reference condition to 'move away from'.

Thirdly, an analytical or process-based approach that employs empirical models can be used to guide the design of a project. For example, sediment transport functions and empirical knowledge of relationships among channel, sediment and hydraulic variables can be used to guide channel design, determine relationships between sediments and discharge, and generally to assess whether specific restoration actions are appropriate to a site (Skidmore *et al.* 2001). Empirical relationships between habitat and composition or recovery trajectories of biota may guide the selection and placement of different types of in-stream structures (Geist & Dauble 1998). Such methods may be particularly useful when reference conditions are lacking or channel equilibrium is in question.

Fourthly, stream classification systems have been used as a basis for developing guiding images for restoration in North America and Europe. Classification (the ordering of objects into labelled groups based on common characteristics) has been broadly applied to river channels (Rosgen 1994; Poole, Frissell & Ralph 1997), with more than 40 geomorphically based classification schemes employed or proposed in various parts of the world, based on factors such as channel pattern, gradient, bed material size and sediment load (Kondolf *et al.* 2003). Experience to date suggests that classification systems work best as guides to restoration when they are developed for specific regions, like those used to develop the leitbild or guiding image for restoration of German rivers (Kondolf *et al.* 2003). Attempts to develop restoration designs based on application of a single classification system across many environments have led to many failures in North America (Kondolf, Smeltzer & Railsback 2001) because the specific processes and history of the river under study were not adequately understood.

Finally, common sense may be adequate in many situations, where the guiding image is self-evident and requires little or no expert analysis. All restoration projects need not be preceded by complex and expensive design. For example, areas with no riparian vegetation may simply need to be replanted and streams in farming communities may only need livestock to be fenced out to initiate ecological recovery.

ECOSYSTEMS ARE IMPROVED: THE ECOLOGICAL CONDITIONS OF THE RIVER ARE MEASURABLY ENHANCED

Ecologically successful restoration will induce measurable changes in physicochemical and biological components of the target river or stream that move towards the agreed upon guiding image. Re-establishment of an extirpated fish population, improved water clarity and quality, and establishment of a seasonally inundated meadow following dam removal are readily identified signs of ecological recovery. Such endpoints may take time, and the components being measured will usually have trajectories of different shapes and rates because they differ in their responses to the intervention (Fuchs & Statzner 1990; Molles *et al.* 1998; Muotka & Laasonen 2002). An increase in variability may be a signal of successful restoration because natural systems are inherently variable. However, demonstrating improvement may require evaluation of the variability of the restored river's components with respect to pre-restoration conditions, an undisturbed or less degraded river, or from a process-based understanding of the component dynamics.

How far the restoration project will move a system towards the guiding image will depend on many factors, some of which are non-ecological (e.g. existing infrastructure limitations, stakeholder needs and values, available funding). Additionally, constraints often exist at the catchment scale, including constant factors such as flow barriers (press disturbances) and spasmodic events (pulse disturbances) such as sediment inputs (Bond & Lake 2003). A clear understanding of scale and severity of constraints is needed in order to prioritize restoration activities and arrive at a co-ordinated scheme of activity for the entire catchment (Bohn & Kershner 2002; Roni *et al.* 2002). In some cases, the large-scale constraints are so severe that one must question whether restoration of single reaches is an appropriate use of valuable resources. However, with sufficient watershed planning, the cumulative effects of multiple projects may yield great ecological benefits. Individual projects that are part of a large restoration scheme should be evaluated within the larger context, particularly to determine the effects on other regional projects.

Recognizing the many constraints, we argue that projects are ecological successes when the river is moved measurably towards the guiding image given the ecological and non-ecological contexts. One of the most difficult questions restorationists face is how much restoration-related improvement is enough. The answer lies at the intersection, where defined ecological and stakeholder outcomes are met (Fig. 1) and future efforts benefit from the understanding gained. Restoration success should not be viewed as an all or nothing single endpoint, but rather as an adaptive process where iterative accomplishments along a predefined trajectory provide mileposts towards reaching broader ecological and societal objectives.

RESILIENCE IS INCREASED: THE RIVER ECOSYSTEM IS MORE SELF-SUSTAINING THAN PRIOR TO THE RESTORATION

Ecosystems are subject to changing conditions because of temporal variations in both natural factors and human activities. Ecologically successful river restoration creates hydrological, geomorphological and ecological conditions that allow the restored river to be a resilient self-sustainable system, one that has the capacity for recovery from rapid change and stress (Holling 1973; Walker *et al.* 2002). Natural river ecosystems are both self-sustaining and dynamic, with large variability resulting from natural disturbances. For example, scouring floods can enhance biodiversity by reducing the abundance of competitively dominant species that are favoured by stable flows. There will also be temporal variation in ecological characteristics (e.g. channel alignment, levels of productivity) (Palmer, Ambrose & Poff 1997; White & Walker 1997), although this variability does have limits (Suding, Gross & Housman 2004) and for some rivers it can be predictable. Degraded running water systems (e.g. following dam construction) are typically characterized by a major reduction or alteration in variability (Baron *et al.* 2002; Pedroli *et al.* 2002). Often the limits have been so far exceeded that resilience has been lost (Suding, Gross & Housman 2004).

Unless some level of resilience is restored, projects are likely to require on-going management and repair, the very antithesis of self-sustainability. Thus, we argue that, to be ecologically successful, projects must involve restoration of natural river processes (e.g. channel movement, river–floodplain exchanges, organic matter retention, biotic dispersal). Restoring resilience using hard-engineering methods should not be the first method of choice as they often constrain the channel. However, there are situations in which engineered structures may enhance resilience (e.g. grade restoration facilities that prevent further incision and promote lateral channel movement, Baird 2001; projects providing fish access to spawning reaches through culvert redesign or by establishing pathways to the floodplain, NRC 1992).

NO LASTING HARM IS DONE: IMPLEMENTING THE RESTORATION DOES NOT INFLICT IRREPARABLE HARM

In the last century, Aldo Leopold (1948) stated that the first 'rule' of restoration should be to do no harm. Restoration is an intervention that causes impacts to the system, which may be extreme (e.g. channel reconfigurations). Even in such situations, an ecologically successful restoration minimizes the long-term impacts to the river. For example, a channel modification project should minimize loss of native vegetation during in-river reconstruction activity, and should avoid the fish spawning season for construction work. Indeed, removal of any native riparian vegetation should be avoided unless absolutely necessary. Additionally, restoration should be planned so that it does not degrade other restoration activities being carried out in the vicinity (e.g. by leading to permanent increases in the downstream transport of sediments that are outside the historical range of sediment flux).

ECOLOGICAL ASSESSMENT IS COMPLETED: SOME LEVEL OF BOTH PRE- AND POST-PROJECT ASSESSMENT IS CONDUCTED AND THE INFORMATION MADE AVAILABLE

Ecological success in a restoration project cannot be declared in the absence of clear project objectives from the start and subsequent evaluation of their achievement (Dahm *et al.* 1995). Both positive and negative outcomes of projects must be shared regionally, nationally and internationally (Nienhuis & Gulati 2002). As we gain experience with ecological restoration and document our findings, and should restoration methods prove effective across a range of conditions, it may be logical to reduce the effort invested in assessment.

Determination of when and where restoration monitoring can be reduced is a future challenge. Some projects, such as riparian planting of native trees for bank stabilization, are sufficiently straightforward that the assessment can be periodic visual or photographic checks to ensure that the plants are alive and successfully stabilizing the bank. Other projects, such as in-stream habitat improvement, may be sufficiently common in some regions that only a sample of projects need thorough monitoring and evaluation. A project-by-project determination of the appropriate level and complexity of analysis should be made based on the size of the project and the scale of its likely impacts and benefits (Holl, Crone & Schultz 2003; Anand & Desrochers 2004). In general, the learning potential of a project will depend upon the investment in baseline data, study design and post-project monitoring, but even projects lacking baseline data and post-project monitoring can yield useful insights (Downs *et al.* 2002). Funders and/or regulators of restoration projects should ensure that an appropriate number of projects include broad ecological monitoring and evaluation. A critical first step is for regulatory and funding entities that promote, permit and fund river restoration to create and maintain databases that use a standardized protocol to record where and how restoration is performed. These databases should also maintain and analyse the monitoring information associated with restoration projects.

Assessment is a critical component of all restoration projects but achieving stated goals is not a prerequisite to a valuable project. Indeed, well-documented projects that fall short of initial objectives may contribute more to the future health of our waterways than projects that fulfil predictions. As summarized by Petroski (1985), 'No one wants to learn by mistakes, but we cannot learn enough from successes to go beyond the state of the art'. For example, while post-project monitoring of small-scale fish habitat rehabilitation in lowland rivers of the UK revealed little improvement in habitat conditions, the work identified important issues of scale, site location and water quality that will benefit future restoration efforts (Pretty *et al.* 2003). While the level of monitoring will vary, all restoration assessments should be communicated beyond project proponents and funders to other stakeholders, restoration practitioners, scientists and policy makers.

Ecologically sound restoration: avoiding ineffective approaches

Standards for ecologically successful restoration should inform the design and implementation processes so that the most effective course of action is chosen. Different restoration activities should be selected based on the extent and type of damage, land-use attributes of the catchment, the size and position of the river within the catchment, and stakeholder needs and goals. Even when constraints are significant, there are almost always choices that are more or less ecologically sound, as illustrated by the following four examples.

EXAMPLE 1

A major problem in urban streams is an increase in peak flows because of runoff from impervious surfaces in the watershed. An ecologically effective restoration approach may be to create floodplain wetlands to intercept surface runoff and pollutants and to increase infiltration. An ecologically ineffective restoration approach might involve protecting infrastructure through hard engineering such as rock walls and rip rap. The first approach is more ecologically sound because it improves river conditions by using the natural ability of a healthy river system to cleanse pollutants and moderate flow variability. In addition, this approach requires minimal long-term maintenance and repair and thus is more self-sustaining than many hard-engineered approaches.

EXAMPLE 2

A legacy of timber harvest and log drives in forested areas is a scarcity of wood within river channels and mature trees along river banks. Ecologically effective restoration should include a change in forest management to allow riparian trees to mature as a future source of in-channel wood. An ecologically ineffective activity is placement of wood structures using machinery that causes permanent damage to riparian vegetation, or is intended to 'lock' the channel in place, thereby preventing the natural migration process important for future recruitment of wood to the channel. The former is more ecologically sound because it is based on natural replenishment of wood and does not hinder natural processes. Another example of restoration related to timber harvesting is the increase in structural heterogeneity of streams using boulders which can lead to enhanced ecosystem function (Lepori *et al.* 2005).

EXAMPLE 3

In large lowland rivers, grading, levee breaching or levee widening can be an ecologically effective restoration activity to reconnect the channel with its floodplain. An ecologically ineffective restoration activity would include periodic dredging. The first restores a natural, periodic process that provides many human and ecological benefits, including propagation of native species and natural flood retention. The latter is likely to be costly and less effective ecologically because it has significant, short-term disruptive impacts and relies on regular, costly maintenance.

EXAMPLE 4

Some relatively undisturbed river ecosystems are impacted by upstream impoundments or water withdrawals. In these systems, ecologically effective restoration will move the system closer to the natural hydrograph. Ecologically ineffective restoration will focus exclusively on maintaining some minimum in-stream flow, but will fail to re-establish the natural flow regime. The first approach will be successful in that it may restore cues for fish spawning and riparian plant germination, high flows for nutrient regeneration and channel maintenance, and groundwater connectivity. The latter approach will maintain the river channel but without re-establishing these additional ecosystem benefits.

Implications of setting standards and moving towards implementation

We have described five criteria for ecologically successful restoration, with the goal of encouraging more projects that convert damaged rivers into sustainable ecosystems. This still leaves unanswered questions. Can we actually implement these standards? What types of evaluations are required to determine if a project has met each success criterion? What indicators are meaningful, affordable and repeatable for project evaluations?

Such indicators will vary depending on the nature of the ecological goals, which could range from re-establishing a single species to restoring multispecies communities or ecosystem processes. Additionally, indicators could be selected from two perspectives, one seeks to move away from a degraded state (e.g. show an improvement in water quality relative to pre-restoration conditions) while the other seeks to approach some desired condition (e.g. demonstrate that water quality is closer to values for reference sites). To make effective use of indicators, there must be clear and realistic goals, which will vary greatly depending on context and with restoration procedures. For example, goals and indicators for steep, headwater streams would differ greatly from those for lowland, floodplain rivers.

Selection and use of ecological indicators is now a major area of research, with some excellent lists of the properties of good indicators already available (Davis & Simon 1995; Jackson, Kurtz & Fisher 2000; Dale & Beyeler 2001). In the context of river restoration, we agree that indicators should be easily measured, be sensitive to stresses on the system, demonstrate predictable responses to stresses (i.e. restoration interventions) and, ideally, be integrative. Thus we suggest guidelines for evaluation of each of the five criteria as well as examples of suitable indicators (Table 1).

Ideally, implementation of national and international programmes to evaluate ecological success in restoration would not only advance our understanding of how best to restore streams and rivers, but would also influence the expectations and goals of stakeholders. This issue is also discussed by Jansson *et al.* (2005). However, stakeholder success and/or learning success are possible without ecological success, and are valid criteria for success in their own right (Fig. 1). It is important to emphasize, however, that different forms of success should not be confused. Restoration projects should not be labelled ecological restoration unless they meet the five criteria we outline. For example, if river conditions do not improve measurably or are not self-sustaining, but project assessment leads to new ideas for improving the ecological conditions via restoration, then the project could be considered a learning success but not an ecological

Table 1. A provisional summary of guidelines that could be used to evaluate the five criteria for ecologically successful river restoration. The list is not comprehensive. The effort, cost and complexity of the evaluation process should be commensurate with ecological risk, project cost and societal concern. Simple and inexpensive methods should be employed whenever possible. The indicators for each standard are illustrative of possible assessment tools for each criterion, the specific indicator selected for a project will depend on the project focus (e.g. biological, water quality, geomorphic)

	Criteria	Evaluation guidelines	References
1	Guiding image of dynamic state	The guiding image should take into account not only the average condition or some fixed value of key system variables (hydrology, chemistry, geomorphology, physical habitat and biology) but should also consider the range of these variables and the likelihood they will not be static. It should explicitly recognize human-induced changes to the system, including changes in the range of key variables Ideally, this plan should consider local as well as watershed-scale stressors, and should consider how much local restoration can contribute to watershed-level restoration. Indicators: presence of a design plan or description of desired goals that are not orientated around a single, fixed and invariable endpoint (e.g. static channel, temporally invariant water quality).	Poff *et al.* (1997), Bohn & Kershner (2002), Jungwirth, Muhar & Schmutz (2002), Gilman, Abell & Williams (2004), Poole *et al.* (2004)
2	Ecosystems are improved	Appropriate indicators of ecological integrity or ecosystem health should be selected based on relevant system attributes and the types of stressors causing impaired ecological conditions. The expected rate of improvement will vary with the degree of impairment, the degree to which restoration reduces key stressors, and the sensitivity of the selected indicators to changes in stressor levels. Change may be relative to a reference site or away from a degraded state (see text). Indicators: water quality improved; natural flow regime implemented; increase in population viability of target species; percentage of native vs. non-native species increased; extent of riparian vegetation increased; increased rates of ecosystem functions; bioassessment index improved; improvements in limiting factors for a given species or life stage (e.g. decrease in percentage fines in spawning beds or decrease in stream temperature).	Barbour *et al.* (1999), Karr & Chu (1999), Middleton (1999), Bjorkland, Pringle & Newton (2001), Bailey, Norris & Reynoldson (2004), Lepori *et al.* (2005)
3	Resilience is increased	System should require minimal on-going intervention and have the capacity to recover from natural disturbances such as floods and fires, and to recover from further human encroachment. Indicators: few interventions needed to maintain site; scale of repair work required is small; documentation that ecological indicators (see 2 above) stay within a range consistent with reference conditions over time.	Holling (1973), Loucks (1985), Gunderson (2000), Weick & Sutcliffe (2001)
4	No lasting harm	Pre- and post-project monitoring of selected ecosystem indicators (see 2 above) should demonstrate that impacts of the restoration intervention did not cause irreversible damage to ecological properties of the system. Indicators: little native vegetation removed or damaged during implementation; vegetation that was removed has been replaced and shows signs of viability (e.g. seedling growth); little deposition of fine sediments because of implementation process.	Underwood (1996), Biggs *et al.* (1998), Sear, Briggs & Brookes (1998), Steinberger & Wohl (2003)
5	Ecological assessment is completed	Ecological goals for project should be clearly specified, with evidence available that post-restoration information or data were collected on the ecosystem variables of interest (see 2 above). The level of assessment may vary from simple pre- and post-comparisons to rigorous statistically designed analyses (e.g. using before–after, treatment–control or both types of comparisons) but results should be analysed and disseminated. Indicators: available documentation of preconditions and post assessment.	Kondolf (1995), Bash & Ryan (2002), Downs & Kondolf (2002), Downes *et al.* (2002), Gilman, Abell & Williams (2004)

success. Finally, we wish to emphasize that conservation of rivers prior to their degradation should still be the greater priority. Where conservation has failed and crucial ecological services are diminished, restoration that is 'ecologically' sound should be the option of choice (Dobson, Bradshaw & Baker 1997; Ormerod 2003).

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