Freshwater Biology (2007) **52,** 752–769 doi:10.1111/j.1365-2427.2007.01740.x

A strategy to assess river restoration success

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SUMMARY

1. Elaborate restoration attempts are underway worldwide to return human-impacted rivers to more natural conditions. Assessing the outcome of river restoration projects is vital for adaptive management, evaluating project efficiency, optimising future programmes and gaining public acceptance. An important reason why assessment is often omitted is lack of appropriate guidelines.
2. Here we present guidelines for assessing river restoration success. They are based on a total of 49 indicators and 13 specific objectives elaborated for the restoration of low- to mid-order rivers in Switzerland. Most of these objectives relate to ecological attributes of rivers, but socio-economic aspects are also considered.
3. A strategy is proposed according to which a set of indicators is selected from the total of 49 indicators to ensure that indicators match restoration objectives and measures, and that the required effort for survey and analysis of indicators is appropriate to the project budget.
4. Indicator values are determined according to methods described in detailed method sheets. Restoration success is evaluated by comparing indicator values before and after restoration measures have been undertaken. To this end, values are first standardised on a dimensionless scale ranging from 0 to 1, then averaged across different indicators for a given project objective, and finally assigned to one of five overall success categories.
5. To illustrate the application of this scheme, a case study on the Thur River, Switzerland, is presented. Seven indicators were selected to meet a total of five project objectives. The project was successful in achieving 'provision of high recreational value', 'lateral connectivity' and 'vertical connectivity' but failed to meet the objectives 'morphological and hydraulic variability' and 'near natural abundance and diversity of fauna'. Results from this assessment allowed us to identify potential deficits and gaps in the restoration project. To gain information on the sensitivity of the assessment scheme would require a set of complementary indicators for each restoration objective.

Keywords: evaluation guidelines, socio-economics, indicators, floodplain, decision making, bioassessment, sustainability, biodiversity.

Introduction

The adverse impacts of past river developments have been widely recognised in recent years (Malmqvist & Rundle, 2002; Tockner & Stanford, 2002). As a

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consequence, extensive attempts are underway to return rivers to more natural states and to restore lost ecosystem services (Palmer *et al.*, 2004). River restoration, which is defined as the process of returning a river section to a near-natural state (Bradshaw, 1996; Palmer *et al.*, 2005; Roni, 2005), thus has become a priority for water authorities and river managers in many countries (Nienhuis & Leuven, 2001; Holl, Krone & Schultz, 2003; Bernhardt *et al.*, 2005; Yoshimura *et al.*, 2005; Nakamura, Tockner & Amano, 2006). Without being able to prove success, there is a great risk that public support for restoration projects will decline, in particular if one considers that large amounts of money are sometimes involved. However, current restoration projects are often based on trial and error practices (Downs & Kondolf, 2002), whereas systematic approaches guided by clearly defined goals and procedures that would ensure effective use of resources and increase the probability of restoration success are rare (but see Schiemer, Baumgartner & Tockner, 1999; Buijse *et al.*, 2005).

Successful river restoration requires careful consideration of several key elements (Fig. 1). To evaluate the degree to which a river approximates, or deviates from, natural conditions, data from the river prior to impairment or some other sort of reference point are indispensable (e.g. Stoddard *et al.*, 2006). In most industrialised countries, natural reference points no longer exist and complete restoration is not possible. As an alternative, a 'guiding image' can be developed based on historical data and theoretical models (Jungwirth, Muhar & Schmutz, 2002; Jansson *et al.*, 2005; Palmer *et al.*, 2005). Definition of such a 'guiding image', which describes the restoration potential of a river under the given circumstances and constraints, is an important step in the restoration planning

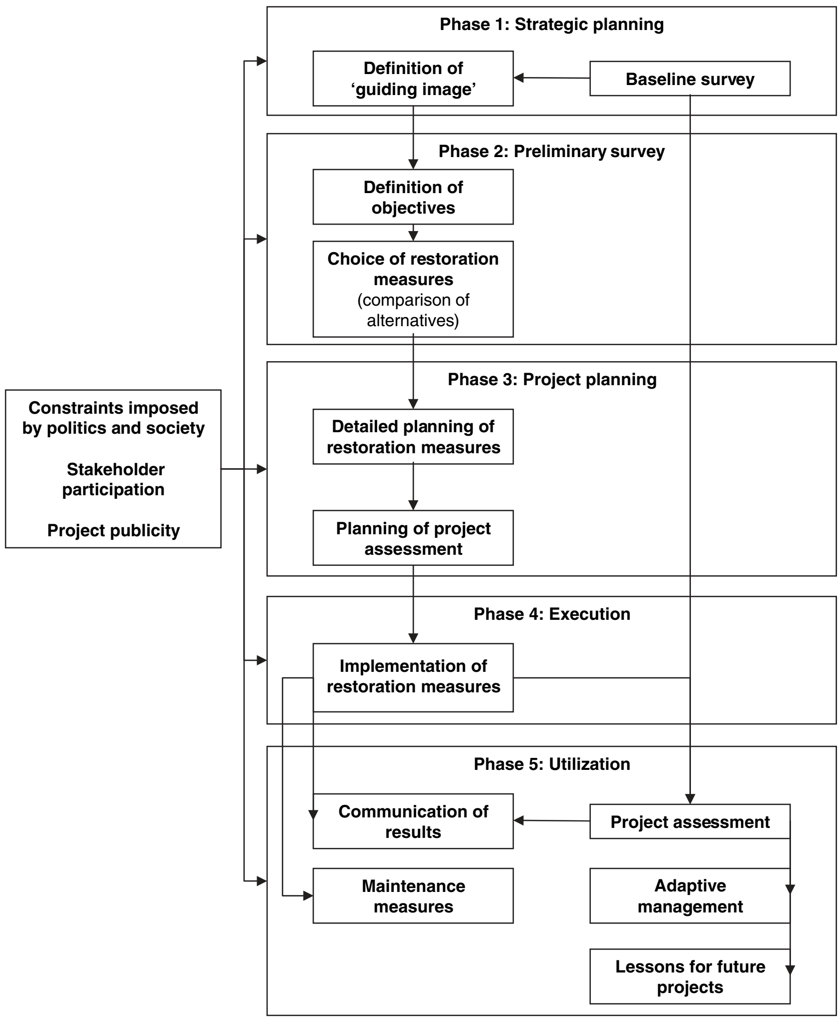

Fig. 1 Proposed strategy to plan and implement river restoration projects (based on Holl & Cairns, 1996).

process. Only once such a 'guiding image' has been formulated, can clear restoration objectives be defined and appropriate restoration measures be selected in an efficient way.

An additional important, but generally neglected element is systematic evaluation whether project objectives were achieved. Such evaluation is critical to detect flaws in project design or implementation and to enable adaptive management or additional restoration measures if objectives are not met. Lessons learnt from both restoration failures and successes are also valuable for future projects and collectively will improve river management and restoration practices (Bash & Ryan, 2002). However, in cases of unsuccessful restoration, benefits for future projects can only be gained if there is a willingness to admit failure (Kondolf, 1995) and to communicate results.

Although scientific, economic and political parties involved in river restoration generally agree that the success of restoration projects needs to be evaluated this is seldom performed (Downs & Kondolf, 2002). Reasons commonly advanced include insufficient funding, time constraints and labour shortage (Bash & Ryan, 2002). These are not compelling reasons, however, given that interviews with river managers in Europe and North America revealed that as little as 5–10% of the total project costs can be sufficient to assess restoration success (Bratrich, 2004). Additional reasons are a lack of evaluation guidelines (but see Jones, 1999; Rutherford, Jerie & Marsh, 2000; Palmer *et al*., 2005) and failure to set clearly defined project objectives before restoration measures are taken.

In this paper, we propose a detailed strategy to assess river restoration success. It consists of a set of guidelines to select among a suite of potential indicators tailored to specific restoration objectives. The proposed strategy was developed for regulatory bodies and river managers involved in river restoration in Switzerland, but they may be adapted to rivers in other European countries and other parts of the world. To illustrate the application of the assessment strategy, we present an evaluation of a restoration project on the Thur River, Switzerland.

A proposed strategy to assess river restoration success

Definition of project objectives. Various physical, chemical and biological processes shape river channels and riparian habitats and hence the distribution of riverine biota (Gregory *et al*., 1991; Beechie & Bolton, 1999). The purpose of river restoration is to re-establish these processes (Bradshaw, 1996). To achieve this goal within the constraints of culturally shaped landscapes, a policy is required that considers three components of sustainability that have been identified (Cairns, McCormick & Niederlehner, 1993; Henry, Amoros & Roset, 2002): social (e.g. protection of people from floods, supply of resources such as drinking water), environmental (e.g. ecosystem resilience, maintenance of natural biodiversity), and economic (e.g. job market). A broad range of factors and processes relevant to successful river restoration are related to these components of sustainability (Table 1). Emphasis in the strategy presented here is laid on environmental objectives, whereas the economic component is not addressed. However, as the number of measurable ecosystem attributes far exceed those that can be reasonably monitored (SER Society for Ecological Restoration International Science & Policy Working Group, 2002), even the list of environmental objectives shown in Table 1 is far from exhaustive.

Over the past three decades, public awareness of ecological issues has generally risen. However, two additional aspects are likely to be vital for the success of restoration projects: project acceptance by the broader public and stakeholder participation. Therefore, it is useful to define these two points also as explicit project objectives (Table 1). Important factors that determine how a restoration project is perceived and hence accepted by the public include greater opportunities for recreational use, improved flood protection, and enhanced ecological conditions of rivers. Typically, sensitivity to specific environmental projects increases strongly when people are directly (e.g. residents close to or landowners of the project perimeter) or indirectly (e.g. local recreation users) affected by the consequences of restoration projects (Selin & Chavez, 1995; Zaugg, 2002). Contrasting interests of stakeholders often result in conflicts (Hostmann *et al*., 2005). Participation of stakeholders in the decision-making process aims to resolve or mitigate such conflicts. If this process is successful, time delays can be prevented and costs of project implementation can be reduced. Involving stakeholders improves credibility of the instigators of a restoration project and enables finding compromise solutions based on stakeholder preferences and concerns (Merkofer, Conway & Anderson, 1997).

Stakeholder participation is thus expected to aid project acceptance. Concepts based on the use of decision analysis techniques exist to structure involvement of both stakeholders and scientists in river restoration decisions (see e.g. Reichert *et al*., 2007).

Indicators to assess restoration success. An indicator is 'a characteristic of the environment which, when measured, quantifies the magnitude of stress, habitat characteristics, degree of exposure to the stressor, or degree of ecological response to the exposure' (Hunsaker & Carpenter, 1990) and 'provides information on the system's condition' (Lorenz *et al*., 1997). Indicators serve as tools to assess, in a quantitative way, the condition of a river in the light of the restoration goals listed in Table 1. When defining indicators according to these objectives, various indicator characteristics need to be considered. They include ecological and social relevance, ease of measurement and interpretation, and cost-effectiveness (Cairns *et al*., 1993; Angermeier & Karr, 1994; Holl & Cairns, 1996; Lorenz *et al*., 1997).

A suite of 49 indicators are proposed to assess whether the 13 project objectives considered most relevant for many river restoration projects in industrialised countries (Table 1) are achieved. Indicators were selected based on information gleaned from the scientific literature and hands-on experience. Both traditional and new indicators are included, and they relate to ecological (river channel and floodplain) and social aspects. The ecological indicators mainly reflect compositional and structural attributes of river ecosystems and their biological communities. Functional (i.e. process-based) indicators may also be included in a comprehensive assessment of rivers (e.g. Gessner & Chauvet, 2002), but indicators relating directly to ecosystem processes are not considered here. However, the present selection of indicators captures functional river ecosystem attributes in an indirect way. Examples include 'short-term leaf retention capacity' or 'food subsidies across land-water boundaries'. In addition, indicators such as 'quantity of large wood' and 'barrier-free migration routes for fish' reflect longitudinal connectivity and can therefore serve as indirect functional indicators of dispersal capacity. For most indicators listed in Table 1 the nature of the parameter to be measured is self-explanatory. However, some require explanation (Table 2).

Many of the indicators in Table 1 can be used to assess more than one project objective. Some are suitable for direct assessment whether an objective has been achieved, others may relate to project objectives only indirectly. For each indicator the person days required for indicator survey and analysis are given. For some indicators (e.g. bedload regime), effort varies greatly with river size and river type. Indicators are selected according to the project's objectives and budget. An additional important consideration when applying these indicators is the time elapsed after restoration measures have been completed. Although most are relevant at all times, some indicators may only become meaningful some time after a river has been restored (e.g. indicators related to vegetation development). Accordingly, indicators were assigned to three temporal categories, depending on whether measurement is appropriate during the first to second, third to fifth or sixth to 15th year after completion of restoration measures (Table 1).

Guidelines to select indicators. The number of potential indicators for river monitoring is infinite and selecting the most suitable ones is not an easy task (Cairns *et al*., 1993). Therefore, guidelines are proposed here to facilitate indicator selection for river restoration projects. In the proposed scheme, it is critical that project objectives are clearly defined from the outset (Fig. 1). Once project objectives have been selected, a suitable, project-specific set of indicators from Table 1 can be selected according to the following guidelines:

1. For each project objective one or, preferably, more indicators are selected. Indicators that pertain to more than one objective are generally recommended to keep the list of required measurements short and assessment costs low.

2. Direct indicators are generally preferred over indirect indicators, because direct indication of an influence is likely to provide more accurate information.

3. If financial or time constraints are important, as is often the case (Holl & Cairns, 1996), selection can be limited to indicators that require low effort.

4. Indicators must be surveyed at an appropriate time in terms of both the number of years elapsed after restoration and of the interannual patterns defined by factors such as season or flood history.

An electronic spreadsheet-based aid was developed for selecting indicators; it can be downloaded at http://www.rivermanagement.ch.

Table 1 Forty-nine indicators in 17 indicator categories to assess river restoration success with regard to 13 restoration objectives considered important (O = direct indicator, ● = indirect indicator; Indicators chosen in the Thur case study are indicated by symbols □ and ■, respectively). Effort levels for surveying indicators and time periods during which surveys are relevant are also given. Indicators marked with an asterisk (*) are commented on in Table 2.

		Service to society		River ecosystem attributes									Implementation		Effort	Relevant time period for survey
Indicator category	**Indicator**	Sustainable supply of drinking water	Provision of high recreational value	Morphological and hydraulic variability	Near-natural bedload regime	Near-natural temperature regime	Longitudinal connectivity	Lateral connectivity	Vertical connectivity	Near-natural abundance and diversity of floodplain vegetation	Near-natural abundance and diversity of fauna	Cycling of organic matter	Project acceptance by stakeholders and greater public	Stakeholder participation	Total number of person days	Number of years after which survey can take place
Project acceptance	Acceptance by interest group *												○		1.5	1-15
	Acceptance by entire public *												○		3	1-15
	Acceptance by project work group *												○		1	1-15
Stakeholder participation	Satisfaction of interest groups with the design of the participation process													○	1-2.5	1-5
	Satisfaction of the public with participation opportunities													○	1-2.5	1-5
	Satisfaction of interest groups with participation opportunities													○	1-2	1-5
Recreational use	Number of visitors		□												1	1-15
	Variety of recreational opportunities *		○												0.5	1-15
	Public site accessibility for recreation		□												0.5	1-15
Landscape	Diversity and spatial arrangement of habitat types *		●	●			●	●	●	●	●	●			3.5-5.5	3-15
	Aesthetic landscape value *		○												1.5-3	1-15
Longitudinal connectivity	Barrier-free migration routes for fish						○								1	1-5
Hydrogeomorphology and hydraulics	Inundation dynamics: duration, frequency and extent of flooding							●				●			0.5	1-15
	Variability of measured wetted channel width *			□	■			□							2.5	1-15
	Variability of visually estimated wetted channel width *			○	●			○							1	1-15
	Variability of flow velocity			○	●										2.5-5	1-15
	Depth variability at bankfull discharge			○	●					●	●				2.5	1-15
Bed load	Bedload regime			●	○		●				●				1-18	1-15
Organic material	Short-term leaf retention capacity			●				●				○			1.5	1-15
	Quantity of large wood	●						●				○			1	1-15
	Quantity and composition of floating organic matter and abundance and diversity of colonizing snails						○	●		●	●	●			1.5	1-5
River bed	Permeability of river bed	●		●	●				○						2.5	3-15
	Diversity of geomorphic river bed structures *			○	●		●	●	●	●	●	●			1.5	1-15
	Temporal changes in diversity of geomorphic river bed structures *			○	●		●	●	●	●	●	●			2	1-15
	Clogging of hyporheic sediments	■		■	■				□						1-1.5	1-15
	Grain-size distribution of substratum *			○	●				●		●				1.5	1-15
	Degree and type of anthropogenic modification			○							●				1	1-15

Determination of indicator values. For each of the 49 indicators in Table 1, a detailed method sheet has been developed (Woolsey *et al.*, 2005; available at http://www.rivermanagement.ch). These method sheets contain information on the ecological and socio-economic relevance of the indicator, the survey method (dimen-

Table 1 (*Continued*)

		Service to society		River ecosystem attributes									Implementation		Effort	Relevant time period for survey
Indicator category	**Indicator**	Sustainable supply of drinking water	Provision of high recreational value	Morphological and hydraulic variability	Near-natural bedload regime	Near-natural temperature regime	Longitudinal connectivity	Lateral connectivity	Vertical connectivity	Near-natural abundance and diversity of floodplain vegetation	Near-natural abundance and diversity of fauna	Cycling of organic matter	Project acceptance by stakeholders and greater public	Stakeholder participation	Total number of person days	Number of years after which survey can take place
Shore	Width and degree of naturalness (vegetation, composition of ground) of riparian zone			○		●		●		●	●	●			1	1-15
	Quantity and spatial extent of morphological units	●		○			●	○			●				1.5	1-15
	Temporal changes in the quantity and spatial extent of morphological units	●		○			●	○			●				1.5-2.5	1-15
	Shoreline length				■			□				■			2	1-15
	Degree and type of anthropogenic modification			○				●	○	●	●	●			1	1-15
Transition zones	Food subsidies across land-water boundaries							●							5.5	1-2
	Exchange of dissolved nutrients and other solutes between river and groundwater	●		●	●	●			○						5.5	3-15
	Community composition and density of small mammals on floodplain							●			○				1	1-15
Refugia	Availability of three types of refugia (hyporheic refugia, shoreline habitats, and intact tributaries)				●		●	●	●	●	●				5.5	1-5
Temperature	Spatial and temporal variation in water temperature *	●				○		●	●						1	1-15
Fish	Age structure of fish population			●	●		●	●			○				4	1-15
	Fish species abundance and dominance			■	■	■	■				□				4	1-15
	Diversity of ecological guilds of fish			■	■	■	■				□				4	1-15
Fish habitat	Presence of cover and instream structures			●	●			●			●	●			1.5	1-15
Macroinvertebrates	Richness and density of terrestrial riparian arthropods							●			○				1.5	1-5
	Occurrence of both surface water and groundwater organisms in the hyporheic zone				●				●		○				4	1-15
	Taxonomic composition of macroinvertebrate community			●	●		●	●	●		○				0.5	1-15
	Presence of amphibiontic species in the groundwater				●				●		○				4	1-15
Vegetation	Presence of typical floodplain species						●			○					0.5	1-15
	Succession and rejuvenation of plant species on floodplains *							●		○					7	3-15
	Temporal shift in the mosaic of floodplain vegetation categories						●			○					2	3-15
	Composition of floodplain plant communities							●		○					0.5	1-15

sion of measurements, procedures, time and effort required, required material, timing and frequency of survey), analysis of results, connections to other indicators, and application examples. The first survey must take place *before* restoration work begins, because evaluation of restoration success is based on a comparison of indicator values before and after restoration. If restoration has already started, a river section similar to the section before restoration may be used as second best choice. The same sorts of surveys are carried out after the restoration measures have been completed. Repeated surveys are recommended to take natural temporal variability into account. As effects of restoration measures may not be immediately visible, sufficient time (at least 1–3 years, depending on the specific indicator) should be allowed for project assessment before definite conclusions about restoration success or failure are drawn. The longer the evaluation period, the more valuable the data are likely to be for assessment (Downs & Kondolf, 2002). Ideally, project evaluation should be carried out until a state of self-regulation (i.e. dynamic equilibrium) is attained. This is, however, rarely feasible (Holl & Cairns, 1996). The frequency of data collection will depend on the indicator being measured and on the project objectives (Holl & Cairns, 1996). In early stages of project assessment, indicators should be assessed more frequently than later, as detailed in the indicator method sheets (Woolsey *et al.*, 2005).

Indicator analysis. Indicator values are determined in various measurement dimensions and so need to be

Table 2 Background information and explanatory notes on selected indicators

Indicator	Comments
Project acceptance	The higher the acceptance of a restoration project by a stakeholder, the easier will be the implementation of future projects in the region. It is recommended that project acceptance is investigated separately for each of three distinct groups of people: (i) stakeholders who are not part of an organised group (interest group); (ii) the broader public; and (iii) stakeholders who are part of an organised work group that participates in project design and/or implementation. Acceptance is assessed by means of interviews and questionnaires.
Variety of recreational opportunities	This indicator is a measure of the attractiveness of a local recreation zone. The range of possible activities (e.g. running, cycling, wildlife observation, bathing, etc.) and the presence of the necessary infrastructure (e.g. cycle paths, access to water, etc.) are examined. Scores are assigned to 12 common recreational activities based on whether the infrastructure required for the individual activities is available or not. Using this evaluation key a final score for the indicator 'recreational opportunities' is calculated.
Variability of visually estimated wetted channel width	Individual river reaches are assigned to one of three categories based on visual assessment in the field: high variability, low variability or no variability. Each sector receives a variability score. An average variability value is subsequently calculated for the examined river section.
Diversity and spatial arrangement of habitat types	Landscape composition and configuration (e.g. patch richness, mean shape index, mean nearest neighbour) are used to calculate the Manhattan Index, which summarises landscape metrics. The Manhattan Index is subsequently assigned to three different categories of change.
Aesthetic landscape value	A poll among the local population is made about the perceived aesthetic value of the restored river landscape.
Availability of three types of refugia (hyporheic refugia, shoreline habitats and intact tributaries)	After disturbance events such as floods and droughts re-colonisation by macroinvertebrates occurs from refugial habitats (e.g. hyporheic zone, shoreline habitats, intact tributaries). The indicator scores the occurrence of such refugia (at three different scales) and is a measure of potential resilience.
Diversity of geomorphic river bed structures	Nine types of geomorphic river bed structures are defined (e.g. backwater and shallow water). A score is assigned to the examined river section depending on the number of different types of structures present.
Temporal changes in diversity of geomorphic river bed structures	The aerial cover of nine types of geomorphic river bed structures is estimated at various points in time. Flood events reshape and create such structures; therefore, change in their aerial cover over time is an indicator of a river's morphological dynamics.
Grain-size distribution of substratum	The relative proportions of five grain-size categories are visually estimated.
Spatial and temporal temperature heterogeneity	Continuous measurement of surface water temperature over time using temperature loggers or infra-red imaging from helicopter.
Succession and rejuvenation of plant species on floodplains	This indicator measures the composition, spatial distribution and temporal dynamics of floodplain vegetation.

Table 3 Proposed matrix to evaluate restoration success in five categories by comparison of standardised indicator values before and after restoration measures are taken

		Indicator value before restoration										
		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Indicator value after restoration	0.0	0	−	−	−	−	−	−	−	−	−	−
	0.1	+	0	−	−	−	−	−	−	−	−	−
	0.2	+	+	0	−	−	−	−	−	−	−	−
	0.3	+	+	+	0	−	−	−	−	−	−	−
	0.4	+	+	+	+	0	−	−	−	−	−	−
	0.5	++	++	+	+	+	0	−	−	−	−	−
	0.6	++	++	++	+	+	+	0	−	−	−	−
	0.7	++	++	++	++	++	+	+	0	−	−	−
	0.8	+++	+++	++	++	++	++	+	+	0	−	−
	0.9	+++	+++	+++	+++	+++	++	++	++	++	0	−
	1.0	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	0

Symbol for success category: −, deterioration, failure; 0, no change, failure; +, slight improvement, small success; ++, medium improvement, medium success; +++; strong improvement, large success.

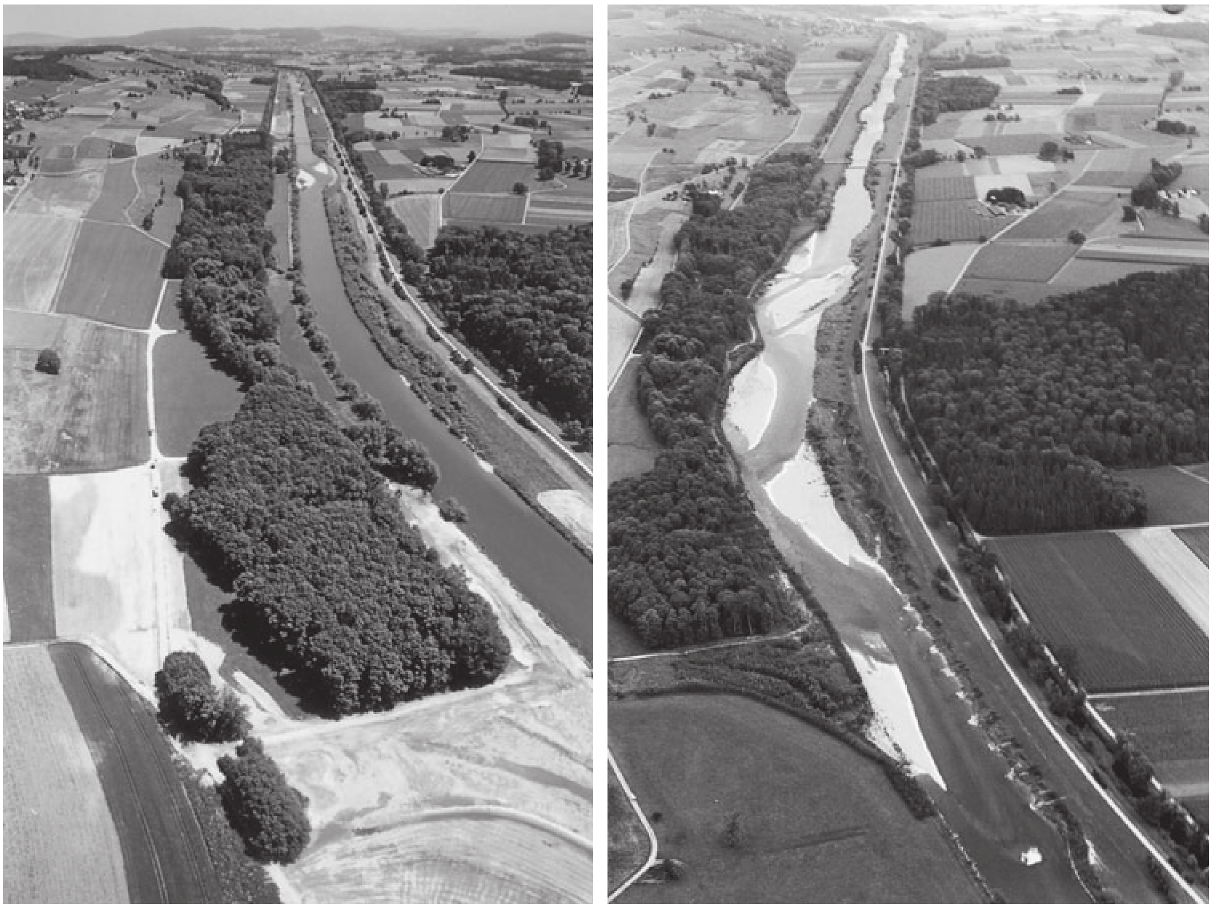

Fig. 2 The Thur River near Schäffäuli, Switzerland, before restoration in June 2001 (left photo) and after restoration in May 2004 (right photo) (Photos by C. Herrmann, BHAteam, Frauenfeld, Switzerland, with permission).

standardised before calculating an overall dimensionless evaluation score between 0 and 1. The reference condition, which is assigned the value 1, often corresponds to the undisturbed state before large-scale industrial disturbances and the beginning of intensive agriculture or forestry (for industrialised

Table 4 Summary of the Thur River case study near Schäffäuli, Switzerland: rationale, survey, analyses and results

	Direct indicators for objective 'provision of high recreational value'		Direct indicators for objective 'near-natural abundance and diversity of fauna'	
	Number of visitors	Public site accessibility for recreation	Fish species abundance and dominance	Diversity of ecological guilds of fish
Rationale				
Rationale for selecting project objective	Most restored river sections are to improve not only the river's ecological condition, but also aim to provide recreational areas for the local public. Near-natural river landscapes are popular recreational areas. Restoration activities in strongly regulated river sections may therefore create valuable recreational opportunities for the public. Accordingly, accessibility to these areas is of great importance (Nohl, 2001; Junker *et al*., 2003). The restored section may be used for various activities, such as bathing, walking, fishing, horseback riding and picnicking.		Abundance and diversity of fauna are common objectives of restoration measures as they often reflect the overall ability of a restored ecosystem to support near-natural communities. Abundance and diversity of fauna are primarily dependent on the presence of suitable habitats. Habitats for fish, small mammals, macroinvertebrates, amphibians, birds and other aquatic and semi-aquatic animals are shaped in particular by morphological and hydraulic variability, a near-natural temperature regime and intact longitudinal, lateral and vertical connectivity.	
Rationale for selecting indicator	This indicator was selected because river widening is known to be appreciated by the public seeking outdoor recreation (Hostmann *et al*., 2005) and the response of the local population to the restoration measure was of interest.	This indicator was selected to evaluate if and to what extent accessibility to recreational sites had been improved by the restoration. Creation of recreational sites is only of value if access to these sites is provided for the public.	This indicator was selected because fish may respond rapidly to restoration and the new habitats created by a river widening. The indicator describes the diversity and dominance structure of the fish community. Results are subsequently compared with typical river-specific reference values. As this indicator also serves as indirect indicator for the objective 'morphological and hydraulic variability', it provides extra information at no additional cost.	The habitats created by river widening offer new resources for fauna. The composition of fish guilds (Jungwirth *et al*., 2003) reflects the availability and variety of resources and is useful to identify a river's potential deficiencies. Guilds refer to groups of species which have similar strategies to feed, use resources other than food, reproduce or migrate in similar ways. This indicator also serves as indirect indicator for the objective 'morphological and hydraulic variability'.
Survey				
Measurement units	Number of visitors per day, divided into different categories of recreational activities	Dimensionless score based on evaluation key that integrates the number and type of possibilities for public access	Dimensionless score based on species number; presence of species characteristic of river type, relative proportion of different species and fish density	Dimensionless score derived from current preferences, structural habitat requirements, temperature tolerances, preferred substrate for spawning, feeding type, migration type, tolerances to pollution and stream degradation and longevity of the fish species present

Table 4 (*Continued*)

	Direct indicators for objective 'provision of high recreational value'		Direct indicators for objective 'near-natural abundance and diversity of fauna'	
	Number of visitors	Public site accessibility for recreation	Fish species abundance and dominance	Diversity of ecological guilds of fish
Survey procedure	The indicator describes the recreational value of a restored river landscape based on the number of people visiting the affected section on pleasant summer days (June–September).	Survey of access opportunities within project perimeter during summer and autumn months determined by a poll; calculation of score based on questionnaire	Identification of expected river-type specific community composition using reference site and/or historical data; survey of current community by semi-quantitative electro-fishing; calculation of score using semi-quantitative scoring matrix proposed in Woolsey *et al.* (2005).	Identification of expected river-type specific composition using reference site or historical data; survey of current community by semi-quantitative electro-fishing; classification of all encountered species into recommended guilds and calculation of number and density of fish in different guilds; calculation of score using semi-quantitative scoring matrix proposed in Woolsey *et al.* (2005).
Effort (person days)	1	0.5	4	4
Required material	Protocol sheets	Standard questionnaire	Electro-fishing equipment; material to store, anaesthetise and measure fish; protocol sheets	Electro-fishing equipment; material to store, anesthetise and measure fish; protocol sheets
Timing and frequency	Before and first summer after completion of restoration measures, repeat at monthly intervals during summer for 3 years	Before and directly after completion of restoration measures, repeat after 2–3 years	Before and directly after completion of restoration measures (two surveys each in the same seasons), repeat for 3–5 years; survey at low water level	Before and directly after completion of restoration measures (two surveys each in the same seasons), repeat for 3–5 years; survey at low water level
Analysis and results				
Measured indicator value	Before: 6 After: 242	Before: 4 After: 7	No numerical value calculated	No numerical value calculated
Benchmarks	0: number of daily visitors before restoration 1: tripled visitor numbers or more	0: 0 scored points 1: ≥10 scored points	According to semi-quantitative scoring matrix	According to semi-quantitative scoring matrix
Standardisation	Linear	Linear	Use of semi-quantitative scoring matrix for direct standardisation	Use of semi-quantitative scoring matrix for direct standardisation
Standardised indicator value	Before: 0 After: 1	Before: 0.4 After: 0.7	Before: 0.5 After: 0.4	Before: 0.4 After: 0.4

Table 4 (*Continued*)

	Direct indicator for objectives 'morphological and hydraulic variability' and 'lateral connectivity'	Direct indicator for objective 'vertical connectivity'	Direct indicator for objective 'lateral connectivity'
	Variability of measured wetted width	Clogging of hyporheic sediments	Shoreline length
Rationale			
Rationale for selecting project objective	Morphological and hydraulic conditions determine a river's channel dynamics and are dependent on a variety of factors (e.g. gradient, discharge depth, river width, flow regime, geometry, flow resistance). Lateral connectivity ensures the connection and exchange of material and organisms between aquatic, semi-terrestrial and terrestrial habitats. Comprehensive river regulation measures in the 19th century have greatly reduced morphological and hydraulic variability and lateral connectivity in the Thur River.	Suspended particles in downwelling river water can clog the pores of river sediments. This clogging process or 'colmation' (e.g. Boulton, 2007) causes reduction in vertical exchange of ground and surface water and in oxygen transport into the hyporheic sediment. In addition, it can affect various ecological processes, such as development of fish eggs and habitat conditions for macroinvertebrates (Boulton, 2007).	The aquatic–terrestrial interface along rivers is important for facilitating biotic and abiotic exchange between the river channel and its adjacent riparian area.
Rationale for selecting indicator	As river widening typically affects the variability of wetted channel width, this indicator was considered highly suitable for evaluating morphological variability. The spatial variability of wetted channel width is one of several parameters determining habitat quality of rivers. In straightened river sections, variability of wetted channel width is close to zero. In widened river sections they typically vary at least two- to three-fold. As the indicator also serves the objective 'lateral connectivity', it provides extra information at no additional cost.	This indicator was selected because it enables a low-effort and low-cost visual estimation of the degree of clogging based on a method commonly applied in Switzerland.	Because shoreline length is proportional to the extent of the aquatic–terrestrial interface, it is an ecologically meaningful indicator to assess lateral river connectivity (see Paetzold, 2005). It also reflects the geomorphological complexity of a river section and is a quantitative measure for the availability of aquatic and riparian habitats. In dynamic river channels, shoreline length can be up to 25 km per river km and remains high throughout the annual discharge cycle (Tockner & Stanford, 2002). In channelised rivers, shoreline length is low at about 2 km per river km and varies little with discharge.
Survey			
Measurement unit	Coefficient of variation (%) of wetted river channel width	Estimate of proportion of fine particles on river bed (%) in five clogging classes	Ratio of shoreline length to river length (km km^{-1})
Survey procedure	Measurement of 50 or more sites perpendicular to flow direction; distance between sites ≤10 m and ≥50 m	Estimation of degree of clogging at 20 sites or more per 1000 m of river length and assignment to one of five clogging classes ranging from 'no clogging' to 'complete clogging' following Schälchli (2002)	Determination of historical shoreline length from maps and aerial photographs; measurement of current shoreline length by walking along perimeter of wetted channels and pools with a differential GPS (dGPS) at medium flow; generation of map and subsequent calculation of current shoreline length with GIS.

Table 4 (*Continued*)

	Direct indicator for objective 'morphological and hydraulic variability' and 'lateral connectivity'	Direct indicator for objective 'vertical connectivity'	Direct indicator for objective 'lateral connectivity'
	Variability of measured wetted width	Clogging of hyporheic sediments	Shoreline length
Effort (person days)	2.5	1–1.5	2
Required material	Measuring tape or laser distance measuring device, protocol sheets	Protocol sheets, classification scheme by Schälchli (2002)	Differential GPS and GIS-software, historical maps
Timing and frequency	Two surveys before completion of restoration measures and three surveys after first flood event affecting morphology of the restored section; one additional survey following second flood event and thereafter 1–4 annual surveys	At least two surveys before completion of restoration measures and one further survey 4–6 weeks after first flood event affecting stream morphology of the restored section; additional surveys at 3-month intervals	Before and in first year after completion of restoration measures; repeat at 5-year intervals
Analysis and results			
Measured indicator value	Before: 3% After: 19%	–	Before: 2.02 After: 2.80
Benchmarks	0: 0% 1: ≥ 65%	0: complete clogging 1: no clogging	0: 2 km km^{-1} 1: 4.47 km km^{-1} (calculated from historical maps)
Standardisation	Linear	Numerical coding of Schälchli's (2002) qualitative classification: Complete clogging = 0 Strong clogging = 0.2 Moderate clogging = 0.5 Slight clogging = 0.9 No clogging = 1	Dividing the current shoreline length at medium flow by the reference (i.e. historical) shoreline length at medium flow results in a standardised value between 0 and 1.
Standardised indicator value	Before: 0.04 After: 0.29	Before: 0.5 After: 0.6	Before: 0 After: 0.3

European countries: mid 1800s) (Nijboer *et al.*, 2004). In many countries (including Switzerland), such pristine conditions no longer exist and a return to such conditions is not realistic. Therefore, realistic, maximally attainable, near-natural reference conditions are used as a benchmark (i.e. as an 'operational guiding image' *sensu* Jungwirth *et al.*, 2002). Methods currently in use to establish reference conditions are the use of historical data, data from reference sites elsewhere with similar characteristics, theoretical models and expert judgement (Nijboer *et al.*, 2004). Measured indicator values are standardised according to an indicator-specific equation or a semi-quantitative or qualitative classification scheme. For all indicators, recommended reference values and standardisation equations or tables are given in the method sheets in Woolsey *et al.* (2005).

Assessment of overall project success. Overall project evaluation consists of assessing to what extent individual project objectives were met. This is achieved by averaging all standardised indicator values relating to a given project objective before and after restoration and comparing the resulting values in five success categories (Table 3).

The Thur assessment: a case study

Introduction. The Thur River is a 127-km-long tributary of the Rhine River with a catchment size of 1750 km^2. Lakes or reservoirs, which could buffer high flows, are absent along the Thur River, and the combination of heavy rainfall, snowmelt and water-saturated soils can cause a dramatic increase in river discharge within a few hours. Extensive floods in the 19th century resulted in the introduction of comprehensive river regulation measures for flood protection. However, further heavy flooding events followed in the 20th century (http://www.rhone-thur.eawag.ch), and after a major flood in 1978, when peak discharge exceeded mean annual discharge 30-fold, planning began for further regulation measures. The main goals of the project were to improve flood protection, to provide recreational space for people, and to increase the ecological conditions of the river including its floodplain. The measures were begun in 1987 (Canton of Zurich) and 1993 (Canton of Thurgau) and will continue until 2015. The main ecological deficiencies identified were lack of habitat for flora and fauna, a disturbed sediment regime, lack of river channel dynamics, and lack of longitudinal and vertical connectivity.

To illustrate the application of the proposed evaluation scheme, success of a restoration project carried out in 2001–2002 on the Thur River near the village of Schäffäuli was assessed. Here the 50-m wide river bed was widened to 100 m along a stretch of 1500 m (Fig. 2).

Methods. In a first step, restoration objectives were selected to evaluate success of the river widening near Schäffäuli. River bed widenings provide rivers with more space to move laterally. As a result, bedload deposition may increase, resulting in stabilisation of the river bed and development of gravel bars and sand banks (Formann, Schober & Habersack, 2004; Peter, Kienast & Woolsey, 2005). Given the geomorphic setting of the Thur River, the channel should also start to become braided and islands should be formed (Schweizer, 2006). Habitat conditions similar to those existing before the first river regulation should develop (see Schmid, 1879). Finally, variability of depth and current velocity are expected to increase, creating characteristic floodplain habitats and causing an associated surge in species richness (Arscott, Tockner & Ward, 2005; Rohde *et al.*, 2006). In view of these expectations and the general project goals, a suite of objectives was selected from Table 1 to evaluate the Thur River restoration (see Table 4 for details).

Indicators for evaluating these restoration objectives were selected based on the four-point guidelines above. We mainly chose indicators that were relevant to more than one of the five restoration objectives that assessed objectives directly (although this was not always possible), required low-effort (with two exceptions) and were suitable for evaluation within 2 years following completion of restoration. To economise on time and effort the size of the indicator set was kept small (total of seven indicators). Rationale for selecting objectives and indicators, information on indicator survey and analysis, and results are summarised in Table 4. The electronic spreadsheet-based aid for selecting indicators was applied in this step.

Indicators were surveyed based on the instructions in their method sheets available at http://www.rivermanagement.ch. A prerestoration survey was not possible because restoration had been completed 2-years previously. Instead, two river sections at Weinfelden-Bürglen and Frauenfeld similar to that of the former un-restored Schäffäuli section served as a prerestoration substitute. Field survey methods for the case study indicators are summarised in Table 4. Indicators were surveyed by different teams on different occasions during the summer and autumn of 2004. Teams consisted of environmental scientists and graduate students in environmental sciences.

Results. Results of the indicator survey at the un-restored sites at Weinfelden-Bürglen and Frauenfeld and at the restored Schäffäuli site are summarised in Table 4 and Fig. 3. The number of visitors to the restored site was 40 times greater than the number of visitors to the un-restored site. Recreational activities that increased most were miscellaneous sports (including cycling, running, fishing, boating and hunting), walking and picnicking (Fig. 3). As a result, the standardised assessment value jumped from 0 to 1. Greatly improved public site accessibility for recreation at the restored than at the un-restored site (standardised values of 0.7 and 0.4, respectively; Table 4) were likely to have been to some extent responsible for the increased number of visitors. Fish species abundance, dominance and density were slightly lower at the restored than at the un-restored site (standardised values of 0.4 and 0.5, respectively), while diversity of ecological guilds of fishes was the same for both sites (standardised values of 0.4). Variability of measured wetted channel width and shoreline length were substantially greater at the restored (standardised values of 0.29 and 0.30, respectively) than at the un-restored site (standardised values 0.04 and 0.0, respectively). Finally, clogging of hyporheic sediments was lower at the restored than at the un-restored site (standardised values of 0.6 and 0.5, respectively).

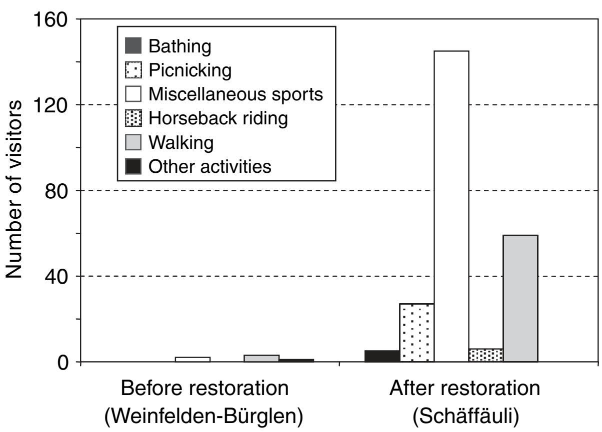

Fig. 3 Number of visitors to the channelized (Weinfelden-Bürglen) and restored section (Schäffäuli) of the Thur River, Switzerland, on a warm summer day.

Overall success categories determined for each project objective were based on standardised indicator values averaged for each objective (Table 5) and the evaluation matrix in Table 3. Results show that the Schäffäuli project was very successful in achieving the objective 'provision of high recreational value'. The objectives 'lateral connectivity' and 'vertical connectivity' were also achieved, although improvements were less pronounced. No change was observed in 'morphological and hydraulic variability', and 'near-natural abundance and diversity of fauna' even declined.

Discussion. The goal of the Thur assessment study was primarily to test the suitability of selected indicators for evaluating river restoration success rather than providing a rigorous assessment of the specific restoration project. For example, we could not apply a before and after survey approach, which may have constrained the evaluation of the specific project. However, our results allow us to draw some general conclusions on the sensitivity and suitability of the proposed assessment scheme.

The Schäffäuli survey highlighted the clear differences in effort required for the selected indicators. Survey of the five low-effort indicators was straightforward, easily organised and completed within two working days, while surveys of the indicator 'variability of measured wetted channel width' (medium effort) and the two fish indicators (high effort) were more time consuming and labour intensive. However, fish may respond rapidly to habitat rehabilitation (Roni *et al.*, 2005) and results from these indicators were therefore deemed to be of particular value in assessing success of the Schäffäuli restoration. The choice of indicators therefore not only depends on project objectives, but also on the restoration measure selected to achieve those objectives.

Method sheets of all surveyed indicators proved to be user-friendly. The survey confirmed that certain indicators can be measured by an instructed amateur. These are the number of visitors; public site accessibility for recreation; variability of measured wetted width; and clogging of hyporheic sediments. Others, however, must be surveyed by trained personnel. Such indicators include fish species abundance and

Table 5 Outcome of restoration success evaluation two years and approximately eight bed-moving discharge events after restoration of a 1500-m stretch of the River Thur near Schäffäuli, Switzerland

	Standardized indicator values by project objective before and after restoration									
	Provision of high recreational value		Morphological and hydraulic variability		Lateral connectivity		Vertical connectivity		Near-natural abundance and diversity of fauna	
Indicator or parameter	Before	After	Before	After	Before	After	Before	After	Before	After
Number of visitors	0	1								
Public accessibility for recreation	0.4	0.7								
Fish species abundance and dominance			0.5	0.4					0.5	0.4
Diversity of ecological guilds of fish			0.4	0.4					0.4	0.4
Variability of measured wetted width			0.04	0.29	0.04	0.29				
Clogging of hyporheic sediments			0.5	0.6			0.5	0.6		
Shoreline length					0	0.3				
Average	0.2	0.9	0.4	0.4	0.0	0.3	0.5	0.6	0.5	0.4
Success category according to Table 2	+++		+		+		+		−	
Name of success category	Large success		No change		Small success		Small success		Deterioration	

dominance; diversity of ecological guilds of fish; and shoreline length.

Discrepancies between individual indicator values characterising the same objective suggest that a set of complementary indicators for each objective is required to increase confidence in the evaluation results. While four indicators were used to evaluate the objective ‘morphological and hydraulic variability’, only one or two indicators were used to evaluate the four remaining objectives. Applying a complementary set of indicators for the individual objectives would enable a more subtle assessment of the project success and, in addition, help to identify potential deficits and gaps in the design of the restoration project. For example, fish (i.e. their composition, density and guild structure) were the only faunal group used to assess the objective ‘near-natural abundance and diversity of fauna’. However, there is evidence that the local fish assemblage in the Thur River is constrained by the available species pool in the catchment (A. Peter, unpublished data). Therefore, the creation of suitable habitats is not sufficient to increase fish diversity at the local scale. In this case, benthic invertebrates and riparian arthropods would probably have been more suitable indicators to assess the effect of increased habitat heterogeneity, expressed by an increase in the variability of wetted channel width and in shoreline length (Paetzold, 2005).

According to the presented evaluation strategy the Thur River restoration project near Schäffäuli was considered successful only with regard to the objectives ‘provision of high recreational value’, ‘lateral connectivity’ and ‘vertical connectivity’. Although it is not surprising that the restoration was more successful in addressing certain objectives more than others, the differences between the categories of success for the five evaluated objectives seem rather large. However, evaluations of the two objectives for which no successes were registered were partly or wholly based on the two fish indicators. As discussed above, these indicators are influenced by factors which were not taken into account in the present evaluation. The use of fish was therefore insufficient for providing an accurate assessment of project success. In contrast, ‘morphological and hydraulic variability’ may have been sufficiently characterised by the two indicators ‘variability of measured wetted width’ and ‘clogging of hyporheic sediments’. An evaluation based on these two indicators would have resulted in a ‘small success’. This example further highlights the need for complementary sets of indicators.

The Thur assessment was based on five objectives which were borrowed from the Thur River restoration project management. As river widenings have effects on many more aspects of a river system (see Methods section), additional restoration objectives should be included in the evaluation. These could provide further information on overall project success or failure, which again may help to adjust the present restoration scheme and are likely to support the design of future widening projects along rivers with similar characteristics as the Thur River. Evaluation of river ecosystem attributes such as 'near-natural bed-load regime', 'near-natural temperature regime', 'near-natural abundance and diversity of floodplain vegetation' and 'cycling of organic matter' may be particularly useful in more comprehensive surveys.

The results of the case study underpin the need for guidelines on how to select complementary sets of indicators that are required to increase the likelihood of drawing correct conclusions from restoration projects. Ideally, assessment strategy are subjected to sensitivity analyses, This can be achieved by systematically testing the effect on assessment scores when indicators are added to or removed from the set. Once the degree of robustness of particular sets of indicators has been established, the goal will be to minimise survey effort while maximising the accuracy and reliability of conclusions on project success.

Evaluation of the River Thur restoration near Schäffäuli focused on individual project objectives only. A general conclusion on overall project success obviously is also desirable. However, such a general evaluation will only be meaningful if based on a comprehensive list of project objectives covering all three aspects of sustainability (Woolsey *et al.*, 2005). As the presented scheme focused primarily on river ecosystem attributes and was limited in scope, no such overall conclusion can be drawn at present. We suggest that, as a rule of thumb, at least five of the nine proposed river ecosystem attributes are assessed (Woolsey *et al.*, 2005) to draw conclusions about a project's overall ecological success, and additional indicators are needed when socio-economic criteria are to be considered as well.

Outlook

The presented strategy to assess river restoration projects is a first step in providing river managers with a tool to assess the success of river restoration. As ecosystems are dynamic and subject to continuous succession and rejuvenation, the outcomes of a restoration project are likely to change over time (cf. Lake, Bond & Reich, 2007). Continuous monitoring to facilitate adaptive management and improve future project designs therefore is an important issue. Lessons learnt from failed projects may prove as valuable as lessons from successful projects (Palmer *et al.*, 2005). In both cases, however, communication of insights is essential for progress to be made towards effectively designing and implementing river restoration projects. Further work is needed to develop strategy that will assess the overall success of restoration projects and that will enable comparison of different projects.

Acknowledgments

The present work was funded as part of the 'Rhone-Thur Project', an inter-disciplinary research project on river restoration involving the following partners: the Swiss Federal Institute of Aquatic Science and Technology (Eawag); the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL); the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) at ETH Zurich, the Laboratory of Hydraulic Constructions (LCH) at EPF Lausanne, the Federal Office of the Environment (FOEN); and the Cantons of Thurgau and Wallis. We acknowledge the useful comments by two anonymous reviewers and by M. Gessner and R. Jansson that helped to improve the quality of this paper. We thank C. Nilsson and R. Jansson (Umeå, Sweden) for the invitation to the 2nd International Conference on Riverine Landscapes.

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(Manuscript accepted 8 January 2007)