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River restoration success: a question of perception

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Abstract. What defines success and failure of river restoration measures is a strongly debated topic in restoration science, but standardized approaches to evaluate either are still not available. The debate is usually centered on measurable parameters, which adhere to scientific objectivity. More subjective aspects, such as landscape aesthetics or recreational value, are usually left out, although they play an important role in the perception and communication of restoration success. In this paper, we show that different perceptions of restoration success exist by analyzing data from 26 river restoration measures in Germany. We addressed both objective parameters, such as hydromorphological changes and changes in fish and benthic invertebrate assemblages, from field investigations, and subjective parameters, such as opinions and perceptions, from water managers via an online survey. With regard to the objective hydromorphological and biotic parameters, our results agree with many studies that have reported improvements in the hydromorphology following restoration; however, there is no similar agreement between results concerning changes in the benthic invertebrate and fish assemblages. The objective results do not correspond to the subjective parameters because self-evaluation of the restoration projects by water managers was overly positive. Indeed, 40% of the respondents admitted that their evaluation was based on gut feeling, and only 45% of the restoration measures were monitored or occasionally checked. This lack of objectively recorded data meant that the water managers were not able to reasonably evaluate restoration success. In contrast, some self-evaluation responses reflected a different perception of the restoration success that was based on landscape aesthetic values or on benefit for the public; others adopted a general "condemned to success" attitude. Based on our data, we argue (1) that goals should be thoughtfully formulated prior to restoration implementation and (2) that it is necessary to monitor river restoration success from different perspectives.

Key words: assessment; EU Water Framework Directive; failure; Germany; goals; monitoring; online survey; ordination; river restoration; success.

Introduction

River restoration has recently become a billion-dollar business, and it is a driving force behind applied ecological science, which is evident from rapidly increasing numbers of publications. There are different drivers for river restoration: increasing awareness of aquatic biodiversity and its value, the wide range of ecosystem services provided by near-natural rivers and floodplains, and legal requirements or international obligations. In the 1970s and 1980s, river restoration was usually limited to improving water quality by reducing organic pollution, eutrophication or inflow of toxic substances. More recently, the focus in North America and Europe has shifted to improving the hydrological and morphological character of channels and floodplains, which is mainly accomplished by restoring local-scale aquatic and riparian habitats either by adding boulders or large woody debris or by re-creating the morphological features of channels. The claim of either success or failure of these restoration measures has been debated for decades (e.g., Palmer et al. 2010), but the picture is incomplete because it remains uncommon to evaluate success with a sound monitoring program or a standardized before-and-after sampling program (Bernhardt et al. 2005, Alexander and Allan 2007, Feld et al. 2007, Roni et al. 2008). This study will neither add to the growing body of restoration effectiveness studies nor will we again debate and hypothesize possible reasons for success or failure;

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instead, we will shed light on another dimension: the perception and communication of success.

"Success" of river restoration measures can be defined with widely different parameters as the basis: abiotic aspects (e.g., related to hydromorphology, hydrology, or substrate), biotic aspects (e.g., biodiversity, functional characteristics, or ecological traits) and socioeconomic aspects (e.g., recreational value, ecosystem services, or policy). More generally, river restoration success can be judged based on objective (i.e., measurable) parameters and on subjective parameters, which involve preferences, feelings, or aesthetic values. Both the objective and subjective parameters may be subject to change, e.g., if definitions of reference conditions are adapted or if societal attitudes change.

In a recent study, Woolsey et al. (2007) developed an extensive indicator set of 49 parameters that covers the three aspects mentioned above; though, only measurable, quantifiable parameters were included, which is typically the case. However, there is no doubt that subjective parameters play an important role in the perception and communication of restoration success. Water managers or municipal politicians often communicate a "success story" of a river restoration project, while results based on objective parameters might be more divergent concerning the effects on habitats and on assemblages (Muotka and Syrjanen 2007, Jähnig et al. 2009*b*, Weber et al. 2009). It is therefore obvious, but rarely acknowledged, that restoration success is a matter of perspective; however, the societal debate regarding what the ultimate success-indicators in river restoration should be has been missing thus far.

To advance this debate we analyzed the performance of different success indicators for 26 relatively large river restoration measures in Germany; we included both analysis of hydromorphological and biotic parameters based on field investigations and the perception of water managers recorded via an online survey. Our goal was to (1) compare and relate the objective and subjective parameters to each other and (2) disentangle the different perceptions of success as a basis to discuss the consequences of river restoration practice and monitoring.

Material and Methods

General approach

We sampled and analyzed data from 26 restoration projects, which consisted of both non-restored and restored river sections ("paired sites") in German lower mountain areas and lowlands. The data collected included the following: (1) the perception of success of the restoration measures by water managers via an online questionnaire, (2) hydromorphological changes between the restored and non-restored sections, and (3) biological changes in fish and benthic invertebrate communities between the sections. The selected restoration projects were relatively large, consisted of hydromorphological improvements, and had to be well documented (Appendix A).

Subjective parameters: online questionnaire

Water managers play a key role in restoration projects in Germany with large influence and decision power, thus representing very important players in restoration projects. Getting insights into their perception is therefore crucial for the development of future restoration strategies. An online questionnaire was directed at the executive water managers of the investigated restoration projects, which aimed to (1) evaluate the definition of goals (three questions), (2) evaluate the individual's perception of fulfillment of these goals (five questions), (3) obtain information on barriers to achieving project success and poll major improvement suggestions (three questions), and (4) assemble information on the projects, the institutions, and the role of the respondent within the projects (four questions). From these questions, we chose a subset of the most relevant questions for comparing the perception of success (Table 1).

A total of 139 water managers of the 26 projects were approached, of which 69 water managers from 22 projects responded. If several answers were available per project, the median of the answer was calculated, which resulted in one value for each site.

Objective parameters: hydromorphological and biological data

Data on hydromorphology and biota prior to restoration were not available; therefore, we followed a space-for-time-substitution approach to quantify hydromorphological and biological changes. Each restored section was compared to an upstream non-restored section, which was similar in terms of geology, adjacent land use, and catchment size. Non-restored sections were selected on basis of three parameters: (1) the non-restored section should by similar to the restored section prior to restoration, (2) the non-restored section must be located up-stream of the restored section to avoid an (positive) influence of by drifting organisms from the restored section, and (3) in between the two sections several riffle–pool segments must be present to reduce the risk of organism interchange. Since this parameter depends on stream size the inter-site distances varied between 300 m and 2100 m (one outlier by 7000 m), mean was 750 m without and 1050 m including the outlier. Although this design cannot completely exclude any organism interchange it reflects a compromise between the desired colonization by dispersing organisms into restored sites and a suitable study design. Additionally some bias is accounted for in the German assessment system, which is focusing on reproducing units (e.g., juvenile fish).

All sections were sampled using the same field protocol. Habitat composition was surveyed at two spatial scales, with mesohabitat characteristics of river and floodplains being recorded on 10 equidistant trans-

TABLE 1. Subset of the most relevant questions and the possible answers used in the online questionnaire in this analysis.

Number	Question	Possible answers
1	Were there clear (measurable) goals defined prior to conducting the restoration measures?	none, unclear, medium, precise, very precise, don't know
2	Please state and prioritize these goals from 1 (high) to 5 (low priority).	open answers
3	How do you evaluate overall project success?	none, little, medium, high, very high, don't know
4	What is the basis for your evaluation?	monitoring, spot checks, gut feeling, others, please explain your method
5	How much did changes to the following aspects contributed to your evaluation? (a) Continuity, (b) structure, (c) floodplains, (d) recreation.	none, little, medium, high, very high, don't know
6	How much contribution did your project add to complement the following directives and legal requirements? (a) FFH and birds directive, (b) EU-Waterframework directive, (c) biodiversity strategy, (d) natural conservation (general), (e) landscape (general).	none, little, medium, high, very high, don't know
7	Which improvements could be implemented in future projects?	open answers

Note: FFH stands for Fauna, Flora, and Habitats Directive.

ects within the bankfull discharge area (see Jähnig et al. [2008] for details). Aquatic microhabitats were described by substrate type (Hering et al. 2003), depth and velocity pattern, and these data were recorded at 5 or 10 points along these transects, depending on river width. From these data, eight aggregated metrics were derived: (1) Shannon-Wiener index of channel feature composition, (2) spatial diversity index (Fortin et al. 1999) of substrate composition, (3, 4) coefficient of variation of depth and velocity data, (5) sum of all channel features, (6) mean width, (7) non-fixed shoreline, and (8) profile type (data provided in Appendix B). Generally, restoration measures should increase all metric values. In the subsequent data analysis, we selected metrics that fulfilled two criteria (Table 2): (1) are appropriate on different scales, and (2) cover various habitat aspects, such as substrate distribution, velocity, floodplain habitats and others (Jähnig et al. 2008).

To determine the hydromorphological differences between the non-restored and restored sections we followed the procedure suggested by Jongman et al. (1995): detrended correspondence analysis (DCA) was first applied to analyze the length of the gradient in the data set. Based on the length of this gradient (gradient length <2) principal component analysis (PCA) was applied (CANOCO 4.51; ter Braak and Smilauer 2003). Prior to this analysis, the data were transformed (see Table 2).

Benthic invertebrates and fish were chosen as biological indicators because they provide complementary information because of their different life cycle lengths, different relevant habitat scales, and differing mobility. Both groups have been extensively studied in the river restoration context and are mandatory to use for EU Water Framework Directive (WFD) ecological assessments. The groups were sampled following the national standardized procedures for assessment (Dußling et al. 2004, Haase et al. 2004*a*, *b*). Sampling was performed in the late spring and early summer of 2007 and 2008, and paired sites were sampled on the same day. To evaluate assemblage changes between the restored and non-restored sections, organism data were ranked using nonmetric multidimensional scaling (NMS) with Bray-Curtis dissimilarity as a distance measure (PC-ORD v5.10; McCune and Mefford 2006) and using the flexible beta linkage method. Dissimilarity was calculated with log-transformed abundance data.

As a major driver for restoration in Europe, we were also interested in achievements under the EU Water Framework Directive (WFD), which aims at a "good ecological status" for all rivers by 2015. This status is defined through the biota (aquatic vegetation, benthic invertebrates, and fish fauna) and for all components field, laboratory, and calculation rules are available, including free software to calculate assessment results. Using this freeware Asterics v3.1.1 and Fibs v8.0.6 we calculated the official assessment results (software *available online*).[7,8]

RESULTS

Responses overview

Participants in the online survey agreed that prior to conducting the restoration measure, clear and measurable goals had been either precisely (55.1%) or very precisely (8.7%) formulated (Fig. 1). Success was rated as high or very high (43.5% and 36.2%, respectively). The success rating classes "no" and "little success" were only chosen four times. The evaluations were mainly based on the participants' gut feelings (close to 40%), followed by monitoring and spot checks (25.0% and 22.2%, respectively) and by some other unspecified measures. According to their methodological explan-

[7] ⟨www.fliessgewaesserbewertung.de⟩
[8] ⟨www.landwirtschaft-bw.info⟩

TABLE 2. Spearman's ρ values of aggregated hydromorphological metrics and the scale.

Hydro-morphological metrics	Transfor-mation	Scale	Hydromorphological metrics							
			$CV_{velocity}$	CV_{depth}	SDI	SWI	Profile type	Non-fix	Mean width	Sum
$CV_{velocity}$	none	micro	1.00							
CV_{depth}	none	micro	0.57	1.00						
SDI	none	micro	0.53	0.31	1.00					
SWI	none	meso	0.49	0.60	0.46	1.00				
Profile type	square root	meso	−0.48	−0.63	−0.55	−0.50	1.00			
Non-fix	arcsin(sqrt)	meso	−0.06	−0.15	−0.28	−0.28	0.50	1.00		
Mean width	log	meso	0.23	0.19	0.04	0.25	−0.08	0.19	1.00	
Sum	square root	meso	0.49	0.57	0.47	0.83	−0.43	−0.25	0.25	1.00

Notes: Transformations were applied prior to PCA. Two metrics were removed because they showed autocorrelation during PCA; those selected for PCA are shown in boldface type. Metric definitions are the following: micro, aquatic microhabitats; meso, aquatic and riparian mesohabitats; CV, coefficient of variation; SDI, spatial diversity index (describes composition and spatial pattern of substrate composition); SWI, Shannon-Wiener index of channel feature composition; non-fix, non-fixed shoreline (%), recorded on right and left shore. Profile type ranges from 1 to 7, with more natural profiles having a higher value; Mean width is the mean overall width of sections recorded in meters; and Sum is the sum of all different channel features recorded within a section.

ations, these never followed a standardized procedure. The respondents considered structural changes to have contributed most to this success, with the proportion of high and very high structural change contribution responses summing to 84.1%. Water managers were aware that their projects served a range of directives, and 40% and 65% of respondents reported a high and very high contribution, respectively. However, they viewed the contribution of their projects to add to complement the WFD as significantly larger compared to contributions to other directives and legal requirements (t test of ratings, $P < 0.05$).

Hydromorphological improvements were stated most often as the goal, which was followed by measures to

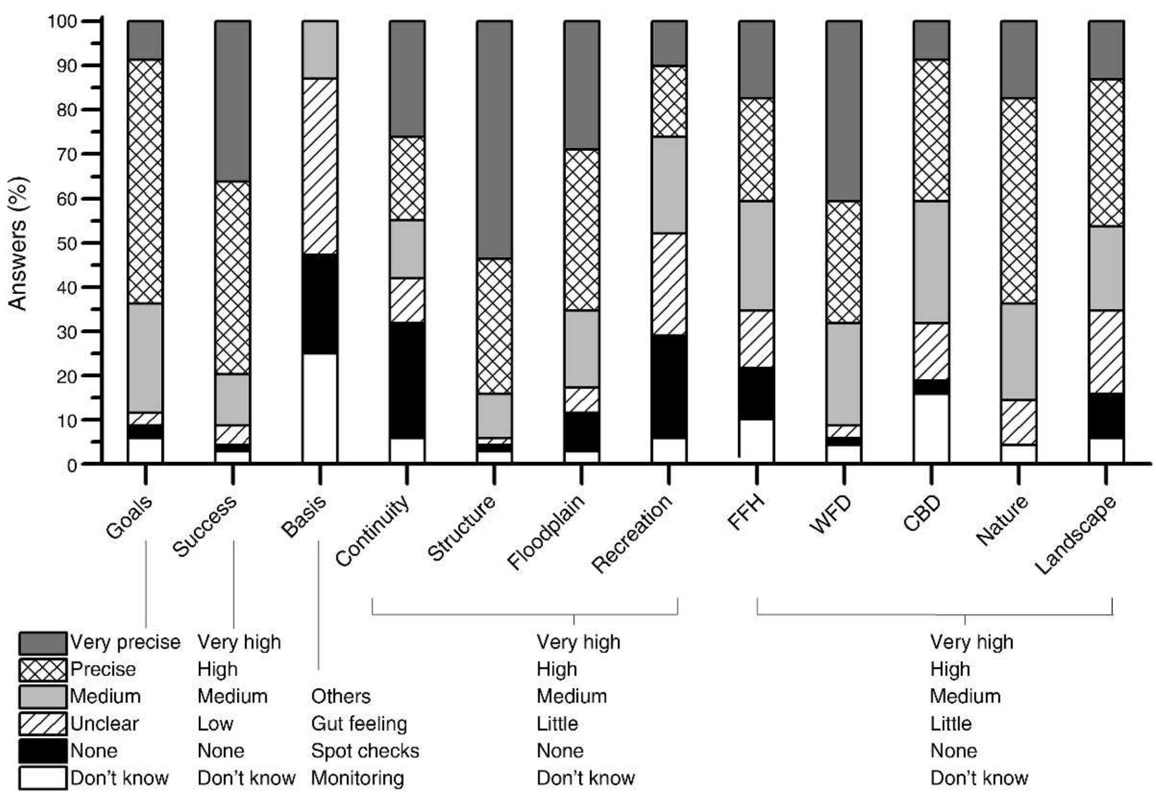

FIG. 1. Distribution of answers to the questions (shortened, details available in Table 2; words shown in italics here denote x-axis labels): Were there clear measurable *goals* defined? How do you evaluate overall project *success*? What is the *basis* for your evaluation? How much did changes in [*continuity, structure, floodplain, recreation*] contribute to your evaluation? Which contribution did your project add to complement [*FFH, WFD, CBD, nature* conservation, *landscape* conservation]? Abbreviations are: FFH, Fauna, Flora and Habitats Directive; WFD, Water Framework Directive; CBD, Convention on Biological Diversity.

TABLE 3. Number and priority of the restoration goals derived from question 2 (Table 2): "Please state and prioritize goals from 1 (high) to 5 (low priority)".

Categorized answer	Priority 1	2	3	4	5
Hydromorphology: structure, dynamics	24	20	4	2	
Continuity	12	3	2	1	2
Floodplain development	7	13	14	6	1
Habitat diversity	7	6	6	5	2
Project development	7	5	1	5	2
Biodiversity	4	5	8	2	
Flood protection	3	5	6	7	5
Water quality		2	5	1	1
Recreational value		1	3	3	4
Public participation			4	2	1

Notes: The answers given were categorized by the authors and ordered from most to least frequent entries within each priority class. Values are the number of responses at that priority level.

improve continuity (Table 3). Goals related to ecological improvements, such as biodiversity or habitat improvement, with the implicit hope of increasing biodiversity, were mentioned far less often.

Perception of hydromorphological changes

Generally, the non-restored and restored sections were hydromorphologically separated; there is an overall clear left-right division in Fig. 2. Four restored and four non-restored sections deviated from this pattern. The first and second PCA axes of six hydromorphological metrics at the 50 stream sections (Fig. 2A) explain 63.9% of the variance in the data set. Eigenvalues were 0.466 for the first and 0.173 for the second PCA axes (eigenvalues for the third and fourth PCA axes were 0.134 and 0.086, respectively). The first axis correlated with both meso- and micro-scale parameters, such as channel element diversity (Shannon-Wiener index channel elements), profile type, substrate distribution (spatial diversity index), and velocity variability (CV velocity). The second axis only vaguely correlated with the proportion of non-fixed shoreline and overall mean width. Restored and non-restored sections are separated. There was no pattern recognizable in the way water managers had rated the success, and even the restored sections that appeared within the non-restored division had been rated as highly successful. In other words, the restoration measures per se were given a successful rating.

Perception of biological changes

The results of the NMS analyses for both benthic invertebrate and fish assemblages show no tendency of restored sections to diverge from their non-restored counterparts in any systematic way (Fig. 2B and C). The numbers of taxa, abundances, and Shannon-Wiener indices only show minute and nonsignificant changes (Sundermann et al. 2011). Again, when comparing the biological changes with the water managers' self-evaluations, no pattern is recognizable to describe why one project was rated as more successful than others.

Achievements of the Water Framework Directive, in terms of their assessment results (Fig. 3), show that 48% of the restored sections achieved a better assessment result for fish, while 20% of sites have a better assessment result in the restored section for invertebrates. In 40% (fish) and 60% (benthic invertebrates) of the sites the assessment result did not change; in 12% (fish) and 20% (benthic invertebrates) of the sites the assessment result showed deterioration. The WFD-required "good ecological status" has not yet been reached in 84% (fish) and 77% (invertebrates) of the restored sections.

DISCUSSION

With regard to the measured hydromorphological and biotic parameters, our results agree with many studies that have reported improvements in hydromorphology; however, the results are mixed with regard to the changes in benthic invertebrate and fish assemblages following restoration (Entrekin et al. 2009, Miller et al. 2010). This does not correspond with the subjective parameters, i.e., the self-evaluation of restoration projects by the water managers, which were mostly positive. In fact, managers rated measures per se as being successful or highly successful. This supports our original assumption that subjective parameters play an important role in the perception and communication of restoration success.

Although some hydromorphological parameters are relatively easy to evaluate, water managers predominantly expressed subjective evaluations. One general rationale might simply be the lack of objectively recorded data: almost no measures were monitored by the executive boards (Fig. 1) and the results presented in this study were not available during the online survey. Additionally, water managers might have had a different idea about restoration success that was based on landscape aesthetic values or benefit for the public, which are commonly reflected by hydromorphological features.

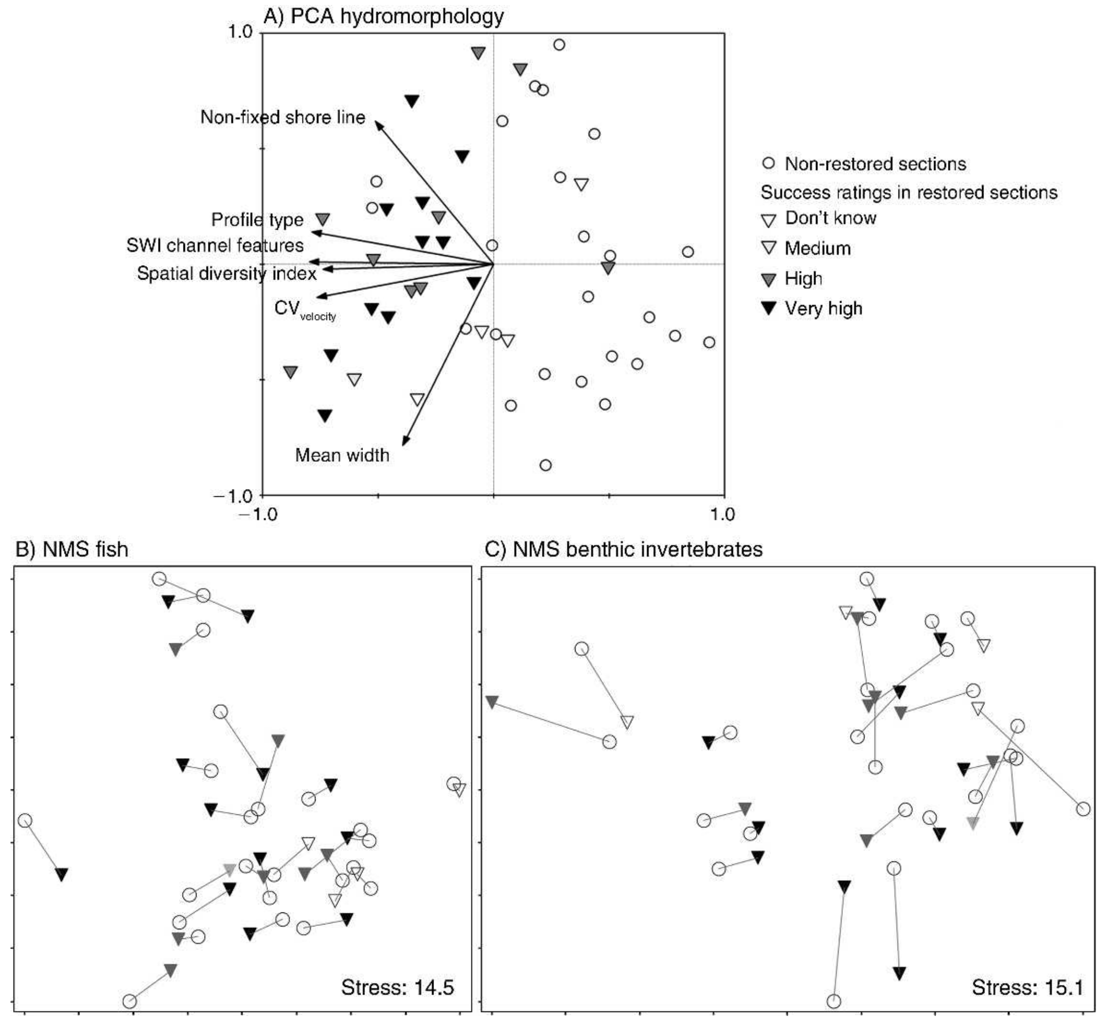

FIG. 2. Ordination diagrams for (A) hydromorphological parameters, (B) fish, and (C) benthic invertebrates. Open circles represent non-restored sections; triangles represent restored sections. The answers "no success" and "little success" dropped out during median calculation. The site of the Rhine River was excluded due to the very different size of the river. Abbreviations are: SWI, Shannon-Wiener index; CV, coefficient of variation. In panels B and C, paired sites are connected by a gray line.

The mismatch between subjective self-evaluation and objective measurements of biological parameters is more difficult to explain. Several projects did not aim to improve biodiversity or to fulfill the biodiversity-related legal requirements; indeed, of the 229 replies regarding their project's goals, only 22 answers from nine of the projects were related to ecology, which included increased biodiversity, improved spawning habitat, or the aims of the Water Framework Directive (Table 3). However, about 60% of the measures were conducted by regional environmental agencies, which are obliged to fulfill the legal requirements of the WFD, i.e., reaching a "good ecological status" in all rivers by 2015. This goal is likely to be missed by 70% of the rivers in Europe (EU Commission 2007), including most of the investigated sections (Fig. 3). It thus seems more likely that the respondents were not able to estimate how biotas respond to restoration. Effects on river hydromorphology, on the other hand, can be estimated more easily and were correspondingly more often defined as project goals (yet their success was not measured, see above). This can be further inferred from the answers given to question 2 ("Please prioritize these goals from one [high] to five [low priority]"), where the ecological aims were overambitious, e.g., establishing a near-natural assemblage. There was little perception of the requirements to improve assemblages beyond merely generating in-stream habitats at a local scale. This includes goals such as attaining the required length of near-natural sections to have self-sustaining populations, establishing source populations to recolonize restored sections, and meeting the time spans required for recolonization (e.g., Bond and Lake 2003, Pretty et al. 2003, Harrison et al. 2004, Hughes 2007, Jähnig and Lorenz 2008), or goals generated by considering the "ghost of land use past" and the remaining stressors (Harding et al. 1998, Giller 2005,

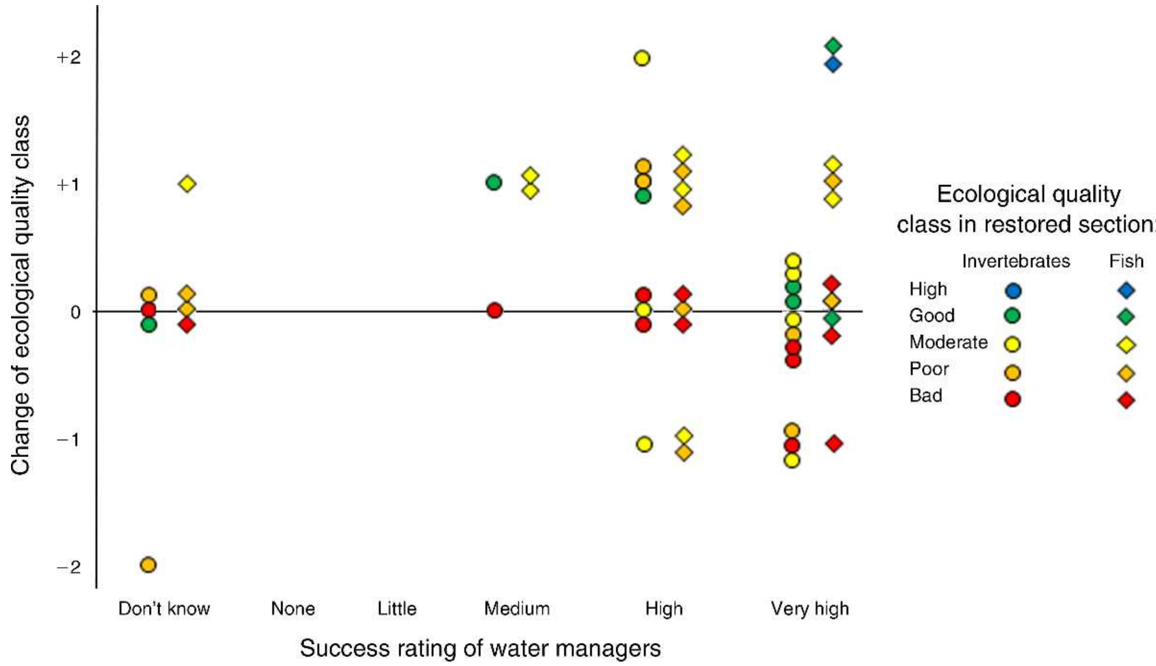

FIG. 3. Comprehensive diagram showing the official ecological quality class (EQC) results for invertebrates and fish in the restored sections, the answer of water managers to question 3 from Table 2, "How do you evaluate overall project success?" (*x*-axis), and the differences in the EQC results between non-restored and restored values (*y*-axis; values above zero indicate improvement; values below zero indicate deterioration).

Hilderbrand et al. 2005, Sondergaard and Jeppesen 2007, Langford et al. 2009). All these parameters have to be considered when planning restoration measures with the goal to improve biodiversity. Scientists have the urgent task of identifying and quantifying the parameters required for an ecologically successful restoration (Palmer 2009) because, at the moment, hypotheses addressing the poor biological response to restoration are rarely based on empirical data.

In addition to the unintended overestimation of restoration success, there is a third highly subjective argument: from a water manager's perspective, restoration measures are "condemned to success." If measures are not immediately successful in reaching legal requirements, such as those of the Water Framework Directive, then river restoration might be seen as a waste of money and might come to a halt. This argument is supported by the water managers' surprising awareness of problems and their numerous suggestions for improvements of restoration efforts, despite their generally positive evaluation of the project's success (Table 1: question 7). Their suggestions include the following: (1) to improve political and legal factors, especially related to integrated river management or land use changes; (2) to improve the means of project handling, e.g., to achieve more binding results from preliminary discussions; (3) to achieve a better estimation of the biological effectiveness of measures; (4) to increase area availability and pursue large-scale measures, including reallocation of land use; (5) to speed up the approval of projects and shift the approval to lower administrative levels; (6) to strengthen or impose an obligation for post project monitoring and communication of results; (7) to supply more financial means; and (8) to improve participation of stakeholders during all project phases.

From an objective point of view, the poor definition and monitoring of river restoration success (Zedler 2007) has prevented a shift to more successful restoration approaches, especially in terms of biological changes. However, as laid out in the introduction, a societal debate as to what *all* stakeholders might perceive as successful is missing. Definitions of success could include aspects of legal requirements, socio-economic reasoning, health issues, landscape aesthetics, and nature conservation. We thus suggest extended assessment systems to evaluate restoration success. The highly sophisticated long developed assessment systems within the WFD do not account for time lags, ecological constraints (e.g., related to dispersal capabilities or hysteresis effects), or subjective parameters. One of the essential requirements is to formulate clear goals for each individual assessment measure and to then employ an adapted set of success indicators (e.g., Woolsey et al. 2007, England et al. 2008). To enhance the probability of achieving desired biological outcomes, a long-term vision and a linkage of measures to the context of the catchment are required. The agreed-upon indicator set must also consider ecosystem compartments that are not covered in the standard freshwater assessment or monitoring approaches. Riparian vegetation and arthropods, land–water interactions, self purification, denitrification, functional aspects, and ecosystem services have all been shown to react more quickly and more positively to restoration measures than aquatic assemblages do (Lepori et al. 2005, Rohde et al. 2005, Kaushal et al. 2008, Aldridge et al. 2009, Jähnig et al. 2009*a*, Klocker et al. 2009, Palmer and Filoso 2009, Tullos et al. 2009). In addition to these objective parameters, subjective parameters should also be included, such as the sense of landscape beauty perceived by the public and the priceless opportunity to teach children about nature. On the other hand, there could also be a feeling of nuisance from biting midges or a perception of a dangerous riverscape (Le Lay et al. 2008). To include such perspectives would require (expensive) representative surveys of all stakeholders and is an interesting and promising future research topic.

By addressing the contradictory perspectives of success and by disentangling the current different approaches to assess it, we have shown that perspective is extremely important when evaluating river restoration measures. With this study, we hope to contribute to a societal debate regarding what should be considered to be river restoration success indicators and to highlight the necessity of implementing monitoring standards.

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APPENDIX A

Characterization of the restoration projects (*Ecological Archives* A021-091-A1).

APPENDIX B

Diversity of mesohabitats and microhabitats at paired sites (*Ecological Archives* A021-091-A2).