Deliberating options for nature-based river development: Insights from a participatory multi-criteria evaluation

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Abstract:

To address societal challenges in river landscapes, various options are conceivable that differ in the degree of adopting nature-based solutions (NBS) and the respective impacts on people and nature. Multi-criteria evaluation (MCE) can aid participatory deliberations about the performance and significance of such options. However, little experience and evidence exist from the application of participatory MCE in planning NBS in river landscapes. This study aims to expand the understanding of individual and collaborative judgments of agency representatives about river development options with varying levels of NBS interventions. A process tracing approach with a rigorous participatory MCE for four alternatives to develop an exemplary river in Germany is adopted, as well as weighted linear aggregation, descriptive statistics, principal component analysis, and decision tree modeling for data analysis. The results reveal a wide agreement among participants on the positive impacts of NBS on biodiversity and water quality. Participants also tended to judge those ecological dimensions as more important than non-ecological ones. The rankings of alternatives differed when elicited individually but seemed to converge during the deliberation process. Overall, the results indicate a relative preference of participants for medium NBS interventions, but also shed light on potential implementation hurdles. The study closes by proposing key questions to consider for MCE of NBS.

Keywords: Multi-criteria evaluation, Nature-based solutions, Participatory approach, River basin planning

1. Introduction

In Europe and beyond, most riverine landscapes have been substantially altered by human interventions to allow for multiple uses such as transportation, settlement, and agriculture, with consequences for the biophysical qualities of river basins and thus the provision of riverine ecosystem services (Ekka et al., 2020). Hydraulic engineering structures such as dams, dikes, weirs, locks, and canals disrupt the longitudinal connectivity of rivers and floodplains, thereby impairing the transport and delivery of sediments and nutrients as well as the migration and dispersal of aquatic species (Zarfl and Lehner, 2020). The impact of river modifications also manifests in the fact that 60% of surface water bodies have not yet achieved the good or high ecological status required by the Water Framework Directive (EEA, 2018). Especially in Germany, there is still a lot of ground to make up. The latest report on the status of floodplains for the 79 largest rivers in Germany shows that around 92% of floodplains are significantly to very severely impaired and only one third of morphological floodplains still serve as natural flood retention areas (Koenzen and Günther-Diringer, 2021).

Nature-based solutions (NBS) offer a promising alternative to hydraulic engineering approaches to advance a future-proof river landscape development for people and nature (Albert et al., 2021b). NBS are commonly understood as actions or interventions working with and enhancing nature to address societal challenges such as natural hazards and simultaneously provide environmental, social, and economic benefits (Cohen-Shacham et al., 2016; European Commission, 2015). More nuanced, interventions in river landscapes must work to solve problems of societal interest, employ and promote ecosystem processes, and be practically viable in order to be qualified as NBS (Albert et al., 2019). The degree of interventions in landscapes that deploy and support ecosystem processes to achieve desired outcomes can vary from solutions with no or minimal interventions, such as the creation of protected areas or buffer zones, to profound landscape restructuring, usually by building green or blue infrastructure (Eggermont et al., 2015). Examples of NBS in river landscapes are revitalizing floodplains, removing dams, planting riparian forests, or converting fields into extensive grasslands (Albert et al., 2019; NWRM, 2015). Such NBS have the potential to enhance the delivery of diverse ecosystem services such as water and nutrient retention, groundwater recharge, and biodiversity enhancement and thus contribute to alleviating flood risks, water shortages, and other societal problems.

To date, however, NBS have rarely been considered in planning and management practices for river landscapes (Brillinger et al., 2020; ECA, 2018). Their low uptake suggests difficulties in planning and decision-making. First, NBS typically cross both geographic and sectoral jurisdictional boundaries and affect diverse interests as they usually occur in a landscape context and claim land that is not freely available (Moss, 2007; Nelson et al., 2020; Seddon et al., 2020). Therefore, the planning of NBS normally involves multiple actors with different views and interests regarding the purpose, design, location, and costs of intervention, which can lead to trade-offs and conflicts (Nesshöver et al., 2016). Second, the decision-making context in many cases, including issues such as path dependency, non-supportive actors, unsuitable legislation and inadequate financing, is often inappropriate to harness the full potential of NBS (Schröter et al., 2022). Third, the problem at hand and its solution options may be described and judged from different perspectives, which may complicate joint decision making for NBS, e.g., regarding the level of riverine intervention required to support ecosystem processes (Brillinger et al., 2021; Gómez Martín et al., 2020; Santoro et al., 2019). Fourth, it is difficult to measure or project the performance of NBS, leading to a high degree of uncertainty regarding their viability compared to conventional alternatives (Nadim and Tacnet, 2021; Seddon et al., 2020).

In complex decision-making processes such as the planning of NBS in river landscapes, multi-criteria evaluation (MCE), which integrates participatory and deliberative approaches, has proven to be an appropriate tool to highlight the potential impacts of decision-options, allowing for more transparent and informed decision-making (Estévez and Gelcich, 2015; Langemeyer et al., 2018; Lennox et al., 2011; Messner et al., 2006; Stagl, 2006). In general, MCE methods aim to compare the alternatives considered for decision-making using a set of criteria by which the alternatives are ranked, the preferences or weights that actors assign to those criteria, and an aggregation procedure that combines the criteria-specific rankings into a single rank order, as a compromise of sorts between the different stakeholders' preferences (Proctor and Drechsler, 2003). While there are already numerous MCE applications for water resources management (Hajkowicz and Collins, 2007), flood risk management (De Brito and Evers, 2016), or freshwater ecosystem services (de Castro-Pardo et al., 2021), participatory and deliberative MCE studies on NBS options for river landscapes are rare. A number of studies have begun to use MCE methods that incorporate stakeholder preferences to evaluate the benefits of NBS interventions and rank them relative to other alternatives for addressing urban challenges or for hazard mitigation (Croeser et al., 2021; Liquete et al., 2016; Loos and Rogers, 2016; Ruangpan et al., 2020). However, these studies do not examine different nature-based development pathways of a specific river basin and often only allow stakeholders to weight the evaluation criteria. A consistent and active involvement of actors with a stake in river landscape planning across multiple MCE steps, i.e., in defining NBS options, setting criteria, and evaluating the criteria performance for the NBS options in addition to criteria weighting, has not been exercised so far. Little evidence remains on how responsible persons and administrative boards evaluate different NBS options for river development against multiple implementation criteria, and how deliberations among those involved can inform joint decisions on performance scores and criteria weightings for the NBS options.

The aim of this paper is to shed light on decision-making processes about the uptake of NBS. We focus on two issues: perceptions of administrators regarding the performance of different NBS options, and potential effects of group deliberations on such perceptions. We applied a rigorous MCE approach in a participatory workshop setting to capture both individual and collaborative judgements. We expected that subsequent data analysis would help us exploring relations between administrators' underlying motives, expressed perceptions, and decisions. Such enhanced understanding could foster NBS uptake, among others by reframing and evaluating NBS options in ways that more adequately address stakeholders' knowledge, views, and mandates. Our paper considers river development options with different degrees of NBS uptake in a case study in Germany. Specifically, the following questions are examined:

1. How do the agency representatives of the case study judge the performance of river development options for selected implementation goals and hurdles?
2. How do the agency representatives judge the importance of these selected criteria?
3. What individual rankings of river development options emerge from the performance and weighting judgments of the agency representatives?
4. What explanatory patterns for the individual rankings can be identified from the individual judgments?
5. What collaborative judgments about criteria performance and weighting do agency representatives agree on after deliberating their individual judgments in small groups, and which group rankings emerge?

2. Case Study

This study was conducted as part of a transdisciplinary collaboration between a research project on nature-based solutions and a consortium of agency representatives currently involved in developing a long-term strategy for the sustainable development of a river in Germany. For reasons of anonymity, this consortium will henceforth be named *FutureRiverProject*. The *FutureRiverProject* aims to improve the ecological health and connectivity of a German tributary river with reference to the implementation of the WFD and government's Blue Ribbon program (Bundesprogamm Blaues Band Deutschland)[1], while at the same time enhancing the well-being of the people living along its floodplains. It involves agencies from different sectors and levels, including environmental agencies, infrastructure agencies, and agencies with responsibilities for research and for bundling different sectoral

[1] The central goal of Germany's Blue Belt program is to improve the highly endangered habitats in and along the federal waterways and thus to establish a biotope network of national importance.

interests. Together, these authorities intend to improve the administrative cooperation, train staff in water protection and river basin management issues and facilitate a transparent dialogue with all stakeholders involved. A central product of the *FutureRiverProject* will be an integrated concept that considers both the current use of the river as a federal waterway as well as nature conservation and river ecology.

The aim of the transdisciplinary collaboration was to creatively discuss strategic development scenarios for a specific landscape section of this German tributary river together during a series of workshops and to develop new ideas and approaches to NBS planning and governance. The tributary under consideration has been significantly altered, affecting the linear continuity, water regime, and hydrologic functionality of parts of the floodplain. In addition, there still are discrepancies with WFD objectives to improve the ecological quality of this tributary. Societal challenges that could ultimately be addressed by NBS interventions include achieving good ecological status under the WFD while mitigating and adapting to climate change impacts, such as increased heat stress and flood risks, and addressing multiple stakeholder interests, including agriculture, hydropower generation, recreational boating, tourism, and nature conservation. Therefore, the case study presented in this paper seeks to reveal how members of the *FutureRiverProject* perceive and evaluate selected river development options along a NBS gradient to address the above mentioned, possibly contradicting objectives, and to comparatively discuss the impacts of the suggested NBS options on people and nature.

3. Materials and Methods

3.1. Research design

This study follows a process tracing approach by applying a participatory MCE of different river development options with the *FutureRiverProject*, observing the evaluation and deliberation process simultaneously and then analyzing it systematically. Process tracing as a research strategy in social science attempts to uncover case-specific patterns of manifestations between the independent variable and the outcome of the dependent variable - e.g., to explain a specific (policy) outcome - by examining the underlying (decision) process in detail (Beach and Pedersen, 2019; Collier, 2011). In the current case, the dependent variable is the final outcome of the MCE, i.e., the ranking of river development options, which suggests an individual's or group's possible preference for the respective options. The independent variables are the subjective judgments of the criteria performances and weightings, the deliberation process, and the backgrounds of the participating individuals. Data were collected primarily during a one-day workshop in which the MCE was conducted with group discussions and participant observations. Data analysis is based on a weighted linear aggregation (WLA) model, principal component analysis (PCA), and decision-tree modelling.

3.2. Application of the participatory multi-criteria evaluation

The participatory MCE was divided into three main stages (adapted from Langemeyer et al., 2018): (i) collaborative problem structuring, (ii) deliberative evaluation workshop, and (iii) reflection. The collaborative problem structuring involved the determination of the study area, the development of river development options as alternatives and the definition of the evaluation criteria. The deliberative evaluation workshop comprised individual and group tasks for scoring the criteria performances and eliciting the criteria weights. The reflection included a final discussion on the evaluation of the river development options and the participatory MCE process.

3.2.1. Collaborative problem structuring

The problem structuring was done before the evaluation workshop in collaboration with agency representatives of the *FutureRiverProject*.

3.2.1.1. Determination of the study area

The study area for the MCE was selected according to three aspects: First, the study area should consider a river stretch with a barrage; second, there should be no ongoing *FutureRiverProject* activities or plans in the study area, and third, the study area should have a variety of landscape elements. Consequently, a landscape section of the tributary with a weir was chosen as the study area, covering an area of about 64 hectares and adjacent to a small town. The weir has a boat chute and achieves a water level upstream of about 2.10 m, partly for a sewage treatment plant. The riverbed is straightened, and the riverbanks are mainly stabilized with rockfill, which are often overgrown with vegetation. The river section has an urban character. Apart from the sewage treatment plant, there is a gravel plant, a highway crossing, and other commercial and industrial uses. The floodplain is partly used intensively for agriculture as arable land and grassland. Moreover, there are some biotopes with high to very high conservation value, which are statutorily protected. There is also a hiking and biking trail along the riverbank. However, there are no entry and exit points for boat tourists. The entire stretch of the river would be affected by a flood with a high probability.

3.2.1.2. Development of river development options

Four river development options were developed as alternatives for the study area, differing in the level of interventions at the weir, in the riverbed, in riparian structure, and in land use (Fig.

1). As the MCE did not refer to the ongoing plans of the *FutureRiverProject*, these alternatives are of a theoretical nature, but still with a strong practical relevance. The first alternative (A1) *no NBS intervention* does not contain any river development measures but pursues the goal of preserving the river section in its current form. The second alternative (A2) *minor NBS interventions* aims at ecological optimization of the existing river course, e.g., by partially removing the river embankment, creating a small riparian strip and extensification of agricultural areas near the river embankment. The weir will remain in place. The third alternative (A3) *medium NBS interventions* creates a bypass channel around the weir, which requires structural adjustments to the weir. In addition, a small development corridor for a riparian forest is created and grassland extensification expanded. The fourth alternative (A4) *major NBS interventions* completely removes the weir and rebuilds the historic course of the river section. In addition, a large development corridor is created in accordance with Germany´s Blue Ribbon program in which only extensive agriculture is possible. Apart from the first alternative, the other three alternatives meet the NBS characteristic of ecosystem processes utilization (Albert et al., 2021a). Thus, the fourth alternative employs and supports ecosystem processes of blue-green infrastructure to a greater extent than the other alternatives.

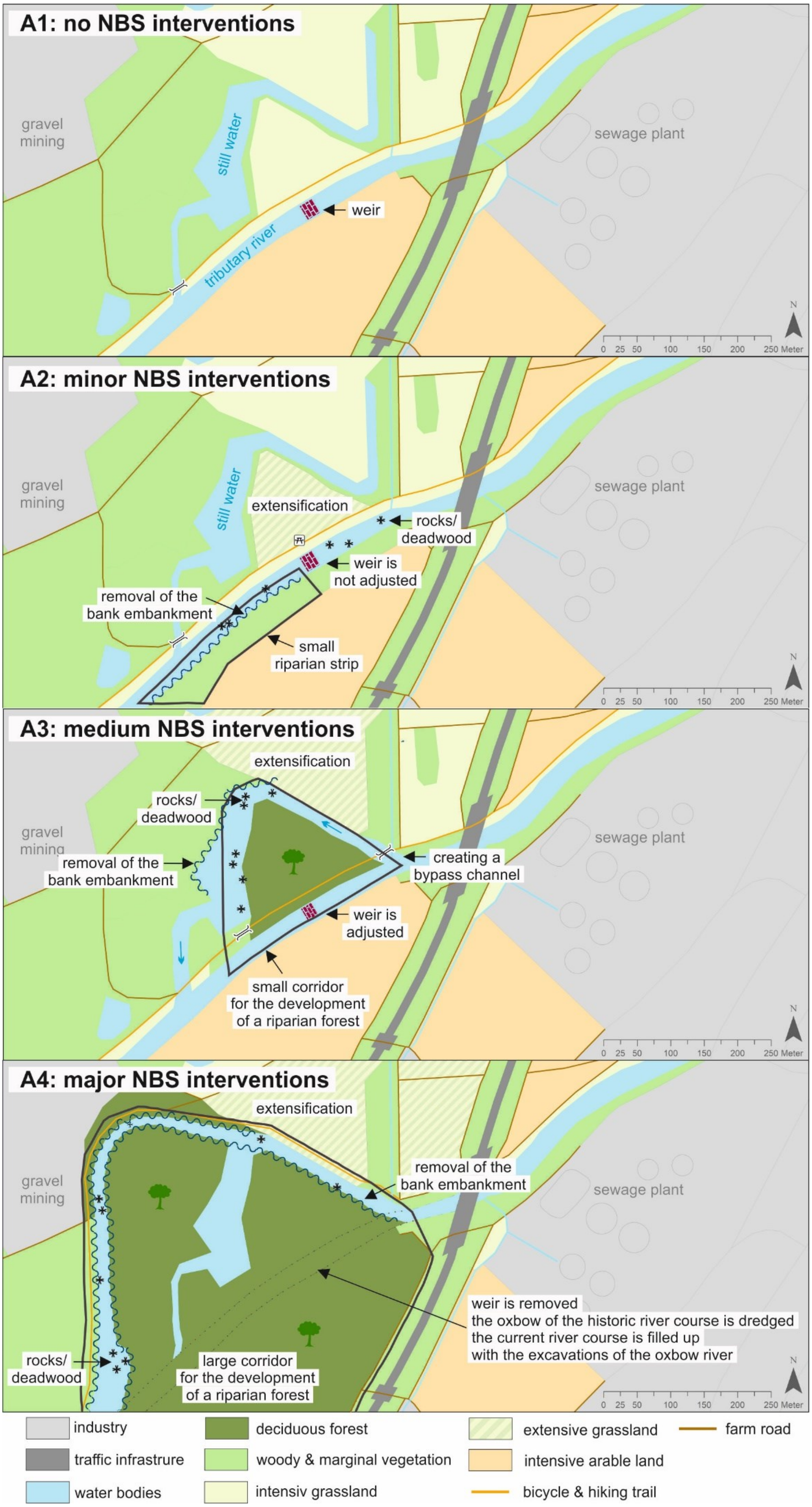

Fig. 1: River development options (A1 - A4) developed in collaboration with members of the FutureRiverProject

3.2.1.3. Definition of the evaluation criteria

Nine implementation criteria were set for evaluating the river development options. Six of the nine criteria refer directly to implementation goals that the *FutureRiverProject* had developed as part of a participation and dialogue process with its stakeholders. The goal criteria are *flood protection*, *sport and leisure boating*, *biodiversity*, *recreation*, *water quality* and *agricultural use of the floodplain*. They represent key societal challenges that are prevalent on the considered tributary but also typical for other rivers in Germany and Europe. Therefore, these goal criteria are attributed to the NBS characteristic of challenge-orientation (Albert et al., 2021a). The other three evaluation criteria point to possible hurdles for implementing the river development options and thus relate to the NBS characteristic of practical viability (Albert et al., 2021a). The criteria on implementation hurdles are *implementation costs*, *effort of decision-making*, i.e., the effort required to reach a decision with the stakeholders involved, and *feasibility* in terms of institutional capabilities and public acceptance.

3.2.2. Deliberative evaluation workshop

The evaluation of the river development options according to the nine criteria took place during a one-day workshop in November 2018. Eleven members of the consortium of the *FutureRiverProject* attended the workshop (Table 1). The participants stemmed from organizations in different sectors (namely environment, infrastructure development, integrated development, or research) and from various levels of governance. The workshop had two main working phases and included deliberation in the form of group discussions and time to reflect on criteria performances and weightings. In the first working phase, each participant individually scored the performance of the alternatives against each criterion and weighted the criteria according to their relative importance. For the criteria performance scoring, the participants were given an impact matrix on which they had to mark a cross on a metric line from 0 (*very negative*) to 1 (*very positive*) for each criterion per alternative (Figure 2A). For the criteria weighting, they had to allocate 100 points among the nine criteria. In both tasks, the participants had the opportunity to note their reasons for the choice of performance scores and weights.

Table 1: Information on the participants of the evaluation workshop

Participant	Sectoral orientation	Authority level	Group membership at MCE-Workshop
P1	Environment	Upper	Blue
P2	Infrastructure	Lower	Green
P3	Infrastructure	Supreme	Green
P4	Environment	Upper	Yellow
P5	Research	Upper	Green
P6	Integrative	Intermediate	Blue
P7	Infrastructure	Supreme	Yellow

P8	Infrastructure	Lower	Blue
P9	Environment	Upper	Green
P10	Integrative	Intermediate	Yellow
P11	Infrastructure	Upper	Yellow

In the second working phase, the participants were divided into groups by the researchers. Based on observations in the previous workshops and interviews with members of the *FutureRiverProject*, the participants could be qualitatively characterized according to their sectoral orientation, project responsibilities, and personal interests to form three inherently heterogeneous small groups (Table 1). In the small groups, the participants had to present their individual performance scores and weightings to the other group members and discuss it with each other (Figure 2A). After the group discussions, participants in a group had to agree on a shared performance score per criterion for each alternative, as well as on shared weights. The shared performance scores were noted on a separate impact matrix. For the weighting task, each group was given 100 game coins to distribute on a pie chart with nine equal parts representing the evaluation criteria (Figure 2B).

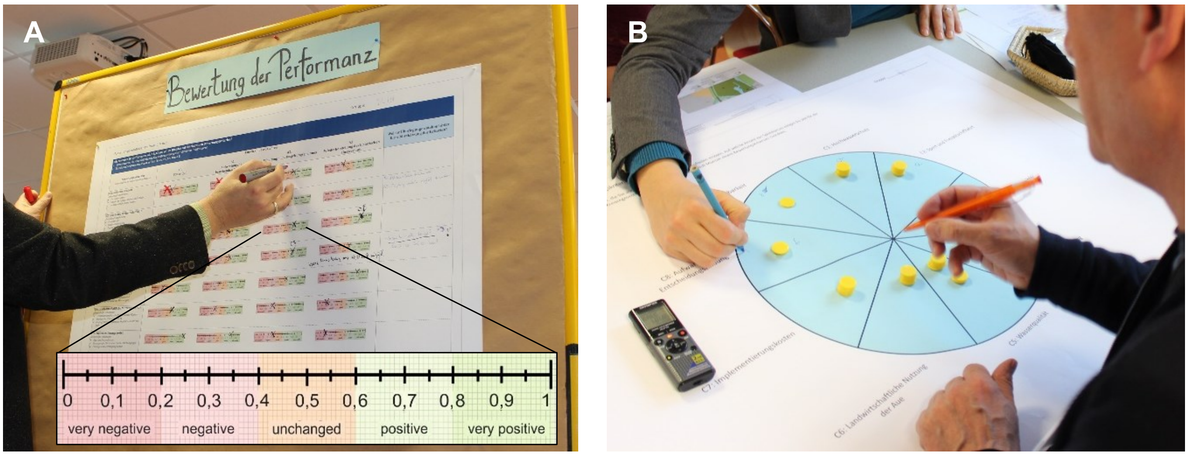

Fig. 1: Criteria performance scoring using a metric line from 0 to 1 (A), and criteria weighting using game coins (B)

During the group discussions, the participants were observed by the researchers. The researchers were divided among the small groups and each wrote a protocol about the group's working style, role behavior, and verbal and nonverbal communication.

3.2.3. Reflection

The reflection phase started at the end of the workshop and was continued after the workshop by questioning the participants individually by telephone. After the three work phases of the workshop, all participants came back to the plenary and the researchers showed the calculated rankings of the alternatives (see 3.3.1.) as well as the respective performance scores and weightings of each group. The participants reflected on the overall MCE outcomes in terms of lessons learned, linkages between the evaluation criteria or among the alternatives, and potential opportunities and barriers to implementation. The questioning by telephone focused on the MCE method and its practical usefulness, perceptions on the decision-making process and weighting, and the development of a shared perspective among the groups.

3.3. Data analysis

3.3.1. Aggregation model

To rank the alternatives regarding their suitability in addressing the criteria, a weighted linear aggregation (WLA) model was used to calculate the sum of weighted performance scores for all criteria. The WLA model is a common aggregation method (Allain et al., 2017) and particularly suitable for participatory MCE methods due to its simple traceability of the mathematical calculation, as it is less perceived as a "black box" (Langemeyer et al., 2018). The rankings in the current case study inform which of the river development options are likely to be considered the most preferred alternative for river development.

3.3.2. Principal component analysis and decision tree modelling

To identify patterns in subjective performance scoring and stated criteria weights leading to a certain alternative more closely, methods of statistical learning were employed that build on the applied MCE procedure. For this purpose, principal component analysis (PCA) was coupled with hierarchical clustering on principal components and a decision tree model. In doing so, relevant patterns of the feature space were explored, and their role in determining participants' preferred alternative along the gradient of NBS interventions through MCE was uncovered.

PCA is a method commonly used for multivariate exploratory analysis that seeks to reduce the number of (often interrelated) explanatory variables through their projection into a set of uncorrelated, linear combinations of original features, i.e., principal components, that describe the principal dimensions of variability (Everitt and Hothorn, 2011; Hastie et al., 2009; Husson et al., 2017; Jolliffe, 2002). The determination of principal components allows the feature space to be explored and relevant features to be identified. Moreover, the dimensionality of data is reduced. This is particularly useful in situations where the number of observations N is low, but the number of predictor variables p is high. This arguably applies to the context of planning and decision-making, where a high number of relevant criteria may be evaluated by a comparatively low number of actors involved (participants). PCA is conducted using the R statistical software with the FactoMiner package (Lê et al., 2008). PCA features include the participants' stated performance scores and the stated weights for all nine criteria. Since both performance scores and weightings are scaled in the range [0, 1], no further normalization of feature data has been considered. Subsequently, cases were clustered using hierarchical clustering on the extracted principal components (Lê et al., 2008).

A decision tree - also referred to as classification tree - is commonly used to describe patterns in data as well as for means of data classification and prediction (Govindaraju and Rao, 2000; Hastie et al., 2009). This is, for example, similar to the application of multiple logistic regression. However, when compared to logistic regression, a decision tree may arguably deliver more easily interpretable models, although no information on the statistical significance of covariates may be revealed. Consequently, through the application of a decision tree, the structure of the MCE decision process can be described, and relevant features linked to specific MCE outcomes, i.e., alternatives along the proposed NBS gradient, can be identified. In this study, the decision tree model was constructed from the principal components, using the R package rpart (Therneau and Atkinson, 2019). Due to the overall small number of observations, parameters for tree construction have been chosen as such that, e.g., the minimum number of observations to attempt splitting and required in terminal leaf nodes is as low as 1, and a split of observations into a training and validation dataset has been omitted to explore the complete feature space. However, accuracy of the tree model was validated against the training set.

4. Results

4.1. Stated criteria performance of the alternatives by participants

In the evaluation workshop, the participants individually judged the performance of the four river development options (A1 – A4) against the nine implementation criteria (C1 – C9) compared to the status quo by stating a score between 0 (*very negative*) and 1 (*very positive*). Table 2 presents all scores of each participant as well as the mean and the deviation between the participants per criterion. On average, the participants anticipated a positive performance on biodiversity (C3), recreation (C4), and water quality (C5), as well as a negative performance on agricultural use of the floodplain (C6), the larger the scale of the river development option. In addition, they stated increasingly negative scores for implementation costs (C7) and effort of decision-making (C8), suggesting that higher costs and effort were expected as the scale of the river development options increased. The greatest deviation between the participants' scores was for sport and leisure boating (C2), implementation costs (C7), and feasibility (C9), while the lowest was for biodiversity (C3). It suggests that the participants had similar perceptions of how the alternatives might affect biodiversity, while their judgements diverged more for costs, navigability, and practical viability.

Table 2: Participants' scoring of the performance of the river development option (A1 - A4)) on each evaluation criterion (C1 to C9). Performances were scored along a metric line from 0 to 1. A numerical value below 0.2 means *very negative* (dark red), below 0.4 is *negative* (light red), between 0.4 and 0.6 is *unchanged* (white), above 0.6 is *positive* (light green), and above 0.8 is *very positive* (dark green).

Evaluation criteria	Alternatives	Participants P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	Mean score	SD per criteria
C1: Flood protection	A1	0.30	0.30	0.40	0.30	0.34	0.20	0.30	0.40	0.40	0.30	0.40	0.33	0.14
	A2	0.30	0.35	0.40	0.40	0.19	0.20	0.30	0.38	0.45	0.60	0.35	0.36	
	A3	0.80	0.30	0.40	0.50	0.63	0.20	0.50	0.60	0.50	0.70	0.70	0.53	
	A4	0.20	0.65	0.70	0.60	0.86	0.30	0.60	0.40	0.70	0.75	0.30	0.55	
C2: Sport and leisure boating	A1	0.70	0.40	0.50	0.40	0.93	0.70	0.70	0.60	0.40	0.50	0.60	0.58	0.17
	A2	0.60	0.50	0.65	0.70	0.25	0.75	0.70	0.40	0.40	0.30	0.65	0.54	
	A3	0.50	0.20	0.50	0.50	0.55	0.65	0.30	0.50	0.60	0.10	0.60	0.45	
	A4	0.70	0.30	0.40	0.30	0.75	0.35	0.30	0.30	0.80	0.70	0.40	0.48	
C3: Biodiversity	A1	0.40	0.20	0.40	0.20	0.16	0.20	0.40	0.20	0.40	0.50	0.30	0.31	0.08
	A2	0.65	0.60	0.50	0.45	0.46	0.60	0.40	0.40	0.40	0.60	0.50	0.51	
	A3	0.75	0.60	0.80	0.65	0.66	0.70	0.70	0.70	0.50	0.70	0.70	0.68	
	A4	0.90	0.80	0.90	0.80	0.83	0.80	0.85	0.80	0.70	0.90	0.90	0.83	
C4: Recreation	A1	0.25	0.70	0.25	0.40	0.39	0.35	0.65	0.60	0.40	0.50	0.40	0.44	0.13
	A2	0.55	0.70	0.30	0.50	0.37	0.60	0.90	0.60	0.50	0.70	0.70	0.58	
	A3	0.70	0.70	0.80	0.70	0.74	0.70	0.70	0.65	0.60	0.80	0.70	0.71	
	A4	0.70	0.65	0.70	0.40	0.66	0.80	0.70	0.30	0.70	0.90	0.40	0.63	
C5: Water quality	A1	0.35	0.30	0.30	0.20	0.22	0.30	0.30	0.20	0.40	0.50	0.30	0.31	0.11
	A2	0.65	0.40	0.60	0.60	0.64	0.55	0.45	0.35	0.40	0.70	0.70	0.55	
	A3	0.75	0.25	0.55	0.40	0.71	0.60	0.65	0.45	0.40	0.80	0.45	0.55	
	A4	0.85	0.65	0.80	0.80	0.81	0.65	0.70	0.80	0.70	0.90	0.90	0.78	
C6: Agricultural use of the floodplain	A1	0.70	0.60	0.80	0.50	0.85	0.35	1.00	0.50	0.60	0.50	0.90	0.66	0.13
	A2	0.35	0.30	0.65	0.30	0.90	0.35	0.70	0.40	0.50	0.35	0.40	0.47	
	A3	0.35	0.30	0.35	0.30	0.35	0.20	0.40	0.30	0.40	0.28	0.40	0.33	
	A4	0.20	0.10	0.10	0.10	0.04	0.10	0.20	0.20	0.30	0.05	0.10	0.14	
C7: Implementation costs	A1	n/a	0.45	1.00	1.00	0.93	0.50	1.00	1.00	0.50	0.50	0.90	0.78	0.20
	A2	0.70	0.60	0.90	0.40	0.63	0.40	0.80	0.80	0.60	0.40	0.50	0.61	
	A3	0.30	0.35	0.40	0.20	0.39	0.30	0.35	0.50	0.80	0.05	0.30	0.36	
	A4	0.10	0.20	0.10	0.10	0.08	0.20	0.10	0.30	0.80	0.03	0.10	0.19	
C8: Effort of decision-making	A1	n/a	0.50	1.00	1.00	0.98	0.50	0.80	0.50	1.00	0.50	0.70	0.75	0.15
	A2	0.70	0.65	0.70	0.40	0.66	0.40	0.70	0.70	0.50	0.60	0.30	0.57	
	A3	0.30	0.40	0.50	0.20	0.46	0.30	0.25	0.60	0.40	0.30	0.30	0.36	
	A4	0.10	0.30	0.05	0.10	0.25	0.20	0.05	0.40	0.20	0.30	0.10	0.19	
C9: Feasibility	A1	n/a	0.50	0.50	0.50	0.99	0.50	0.60	0.30	0.50	0.50	0.50	0.54	0.17
	A2	0.80	0.70	0.85	0.40	0.90	0.45	0.60	0.60	0.60	0.65	0.80	0.67	
	A3	0.80	0.70	0.75	0.30	0.65	0.40	0.30	0.60	0.60	0.40	0.80	0.57	
	A4	0.20	0.30	0.50	0.20	0.25	0.25	0.15	0.45	0.70	0.40	0.70	0.37	

4.2. Weights assigned to the criteria by the participants

Each participant noted how important they considered one evaluation criterion compared to the others by allocating 100 points to the nine criteria. As shown in Table 3, biodiversity (C3) and water quality (C5) received the highest weighting score on average, while sport and leisure boating (C2) and effort of decision-making (C8) predominantly got the lowest scores. Low standard deviations of criteria weights may indicate a consensual position among participants about the criteria importance (Garmendia and Gamboa, 2012). In the current study, the participants set similar scores mostly on the relative importance for sport and leisure boating (C2) and effort of decision-making (C8). The widest discrepancy between participants in one criterion is found for biodiversity (C3) and feasibility (C9). Furthermore, the participants allocated the weightings to varying degrees. For example, participant P7 distributed the 100 points relatively evenly (SD = 2.5), while participant P10 clearly prioritized biodiversity (C3) and water quality (C5) and weighted four criteria with zero, i.e., rated them as relatively unimportant compared to the other criteria.

Table 3: Weightings assigned to each evaluation criteria (C1: Flood protection; C2: Sport and leisure boating; C3: Biodiversity, C4: Recreation; C5: Water quality, C6: Agricultural use of the floodplain, C7: Implementation costs, C8: Effort of decision-making, C9: Feasibility) by the participants. Weights were assigned by allocating a total of 100 points to express the relative importance of one criterion compared to the others.

Evaluation criteria	Participants												
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	Mean	SD
C1	15	20	2	13	20	10	15	3	10	10	12	11.8	5.6
C2	10	10	10	5	10	5	8	10	5	0	5	7.1	3.2
C3	15	20	20	20	20	15	11	20	20	40	12	19.4	7.3
C4	15	10	15	12	10	10	15	20	10	10	5	12.0	3.8
C5	15	10	5	20	20	15	10	12	20	30	12	15.4	6.5
C6	10	10	15	2	10	5	13	7	10	10	5	8.8	3.6
C7	0	5	15	5	5	15	10	3	10	0	15	7.5	5.5
C8	5	5	10	8	5	5	8	5	5	0	5	5.5	2.4
C9	15	10	8	15	0	20	10	20	10	0	29	12.5	8.3
Mean	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1		
SD	5.2	5.2	5.3	6.2	7.0	5.2	2.5	6.9	5.2	13.7	7.4		

4.3. The individual rankings of alternatives of the participants

Through the application of the WLA model, two possible preference rankings of the alternatives were elicited for each participant (Table 4). When all criteria are considered equally important, i.e., each criterion is given a weighting score of 100/9, the alternative with minor NBS interventions (A2) received the highest score on average across all participants. For 8 of 11 participants, equal weighting indicated either no (A1) or minor NBS interventions (A2) as the highest-ranking option for river development. The alternative with major NBS interventions (A4) ranked first only for participants P9 and P10. For participants P1, P10, and P11, however, the total scores for each alternative are very close, making the preference ranking less clear. Considering the individual weightings of the participants, the elicited preference rankings of most participants change. In comparison to equal weighting, the alternative with medium NBS interventions (A3) was identified with the highest mean score. The alternative with medium (A3) or larger NBS interventions (A4) was the highest scored river development option for most participants. Less clear-cut was the ranking with individual weights for participants P3 and P11.

Table 4: Elicited preference rankings of the participants (P1-P11) for the river development options (A1 – A4) based on the overall score per alternative. The overall score is calculated by weighted summation of the performance and weighting scores. Ranking I is based on equal weights. Ranking II is based on the individual weights.

		Participants											
		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	Mean
Ranking I (based on equal weights)	A1	0.300	0.439	0.572	**0.500**	**0.643**	0.400	**0.639**	0.478	0.511	0.478	**0.556**	0.501
	A2	**0.589**	**0.533**	**0.617**	0.461	0.556	**0.478**	0.617	0.514	0.483	0.544	0.544	0.540
	A3	0.583	0.422	0.561	0.417	0.571	0.450	0.461	**0.544**	0.533	0.458	0.550	0.505
	A4	0.439	0.439	0.472	0.378	0.503	0.406	0.406	0.439	**0.622**	**0.548**	0.433	0.462
Ranking II (based on individual weights)	A1	0.335	0.398	0.601	0.402	0.457	0.383	**0.627**	0.406	0.470	0.480	0.530	0.462
	A2	0.573	0.513	**0.619**	0.475	0.475	**0.478**	0.612	0.500	0.470	0.615	0.596	0.538
	A3	**0.670**	0.433	0.588	0.461	0.607	0.468	0.483	**0.578**	0.520	0.698	**0.599**	0.555
	A4	0.523	**0.515**	0.454	**0.506**	**0.662**	0.440	0.438	0.491	**0.650**	**0.800**	0.520	0.545

4.4. Identification of explanatory patterns

By coupling the PCA with a decision tree model, explanatory patterns in the individual performance scores and weightings were identified to elicit likely motivations that help explain participants' preferences towards certain river development options. In a first step, PCA was conducted on the stated performance scores and weights with respect to the elicited rankings of alternatives as described above. The resulting principal components (dimensions) explain 44.6%, 14.3%, and 12.8% of variance, respectively (cf. Figure A1). Using the `dimdesc` function contained in the FactoMiner package that prints correlation coefficients of predictors for each dimension, the elicited principal components are subsequently inspected more closely (cf. Table A2).

With respect to the stated performance scores of the highest ranked alternatives, the first dimension is particularly well explained by the criteria flood protection (C1), biodiversity (C3), water quality (C5), agricultural use of the floodplain (C6), implementation costs (C7), effort of decision-making (C8), and feasibility (C9). More specifically, higher loadings on the first principal component correlate positively with performance scores for the criteria agricultural use (PC6), implementation cost (PC7), decision-making effort (PC8), and feasibility (PC9) – i.e., the higher the loading of a participant on the first dimension, the better the perceived performance of the preferred alternative as guided by the MCE framework. Conversely, lower loadings on the first principal component are in line with lower scores on these criteria. However, such lower loadings tend to correlate with higher stated performance scores for the criteria recreation (PC4), flood protection (PC1), water quality (PC5), and biodiversity (PC3). A similar pattern emerges for the weights given: Higher loadings on the first principal component are positively correlated with higher weightings particularly on decision effort (WC8), implementation costs (WC7), and, to a lower extent, recreational boating (WC2). Lower loadings on the first dimension appear to be associated with higher weights given to the criteria biodiversity (WC3), and water quality (WC5). Concerning the second principal component, higher loadings tend to correlate positively with a higher performance for sport and leisure boating (PC2). Higher loadings on the second component are also correlated with higher weights given for the criteria agricultural use of the floodplain (WC6), and, to a lesser extent, biodiversity (WC3). Lower loadings on the second dimension correlate with a higher importance of feasibility.

The subsequent application of hierarchical clustering on principal components allows the clustering of participants, with four clusters emerging (Figure 3). The first cluster is rather distant to the remaining clusters, comprises only a single participant (P10), and signifies a high weight given to biodiversity and water quality, as well as the neglect of sport and leisure boating and decision-making effort. Similarly distant is the fourth cluster which comprises two members of the supreme infrastructure agency (P3, P7). The participants of this cluster appear to put a higher weight and higher performance score to agricultural use of the floodplain and decision-making effort. In addition, the performance regarding implementation costs is perceived as higher than average. However, the biodiversity performance is considered as lower than average. The second and third cluster do not differ as clearly. The second cluster comprises 5 participants (P1, P2, P4, P5, P8), and the third cluster 3 participants (P6, P9, P11), with both clusters separated primarily by implementation costs. The second cluster is characterized by a lower-than-average importance given to cost, whereas the third cluster is characterized by a higher-than-average importance given to the implementation cost criterion (cf. Table A3).

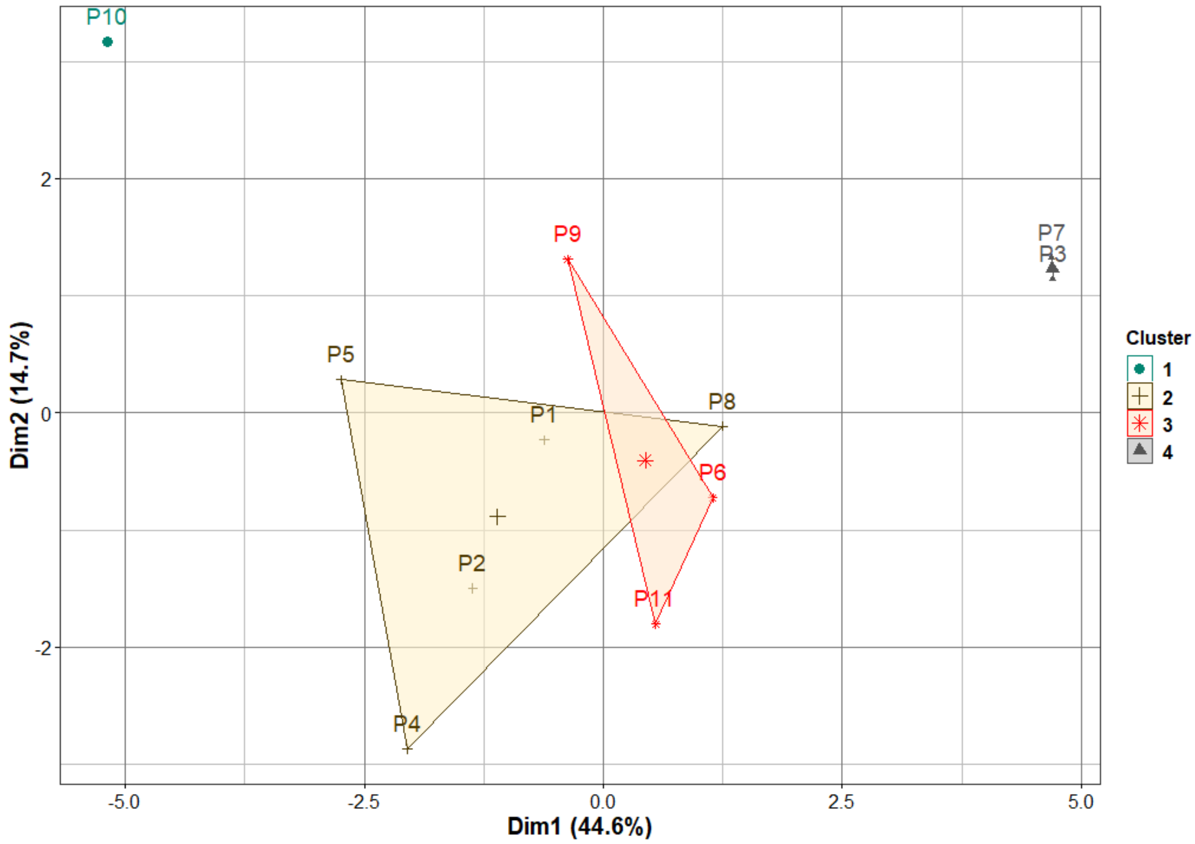

Fig. 2 Clusters of participants elicited through the hierarchical clustering on principal components method.

In a next step, a decision tree model was built to elicit explanatory patterns that point to the preferred alternatives of the participants based on their stated weights and assumed performances of the criteria as guided by the MCE (cf. Figure A4). The decision tree was constructed based on the previously identified principal components, allowing a reproduction of the participatory MCE process with approximately 90% accuracy. Looking at the decision tree, the first principal component appears to express the MCE-guided preference towards larger NBS interventions in the river landscape. It can be seen that very low loadings on the first principal component, associated with a high weighting of biodiversity and water quality, indicate a preference for the alternative with major NBS interventions (A4). At the same time, this alternative is perceived to perform comparatively well with respect to these criteria and additionally with respect to flood protection and recreation. In contrast, higher loadings on the first dimension, associated with greater emphasis on decision effort and implementation costs, suggest MCE-guided preferences for alternatives that are less transformative of the river landscape, while also considering the second principal component. Regarding this second dimension, as outlined above, lower loadings appear to indicate a stronger focus on feasibility. If such a focus coincides with a higher weighting for easier decision-making and lower implementation costs, a tendency towards the alternative with no NBS interventions (A1) can be identified, with A1 being perceived as having a positive impact on agricultural use of the floodplain and sport and leisure boating. The alternatives with minor (A2) and medium NBS interventions (A3) appear to be chosen with gradually increasing emphasis on renaturation aspects as indicated by the first principal component, with a preference towards minor NBS interventions (A1) being associated with a higher loading on this first component and thus a higher weighting of decision-making efforts and implementation costs.

4.5. Group outcomes after discussing the individual performance scores and weights.

The participants, divided into three heterogeneous groups, discussed their individual performance scores and weightings with their group members and then agreed on shared scores and weights for their respective group (Table 5). Overall, it can be seen that the three groups adopted similar performances per criterion for the alternatives as the individual participants. The performance of the alternatives in terms of biodiversity (C3) and water quality (C5) change more positively the greater the NBS interventions in the river section under consideration. The opposite is assumed for the criterion agricultural use of the floodplain (C6): The greater the NBS interventions, the more negative the performance in this criterion will be. Furthermore, the groups expect that the alternatives with no (A1) or minor NBS interventions (A2) will tend to perform worse in terms of flood protection (C1). In addition, A1 is associated with lower implementation costs (C7) and a lower decision-making effort (C8). The greatest difference between the groups in the judgment of the criteria performance is shown in the case of criterion sport and leisure boating (C2). The standard deviation of the performance scores per criterion is much lower between the groups than for the individual participants.

Table 5: The performance scoring and weighting of the evaluation criteria of the small groups after the first and second round of group discussion.

Evaluation criteria	Alternatives	Group Green (P2, P3, P5, P9)		Group Yellow (P4, P7, P10, P11)		Group Blue (P1, P6, P8)		Mean		SD per criterion	
		Perf.	Weig.	Perf.	Weig.	Perf.	Weig.	Perf.	Weig.	Perf.	Weig.
C1: Flood protection	A1	0.30	10	0.30	20	0.30	10	0.30	13.3	0.04	4.7
	A2	0.30		0.30		0.30		0.30			
	A3	0.55		0.50		0.60		0.55			
	A4	0.75		0.55		0.40		0.57			
C2: Sport and leisure boating	A1	0.50	10	0.40	5	0.65	10	0.52	8.3	0.11	2.4
	A2	0.60		0.50		0.60		0.57			
	A3	0.70		0.30		0.50		0.50			
	A4	0.80		0.30		0.40		0.50			
C3: Biodiversity	A1	0.30	20	0.50	20	0.20	15	0.33	18.3	0.05	2.4
	A2	0.50		0.60		0.50		0.53			
	A3	0.70		0.70		0.70		0.70			
	A4	0.80		0.90		0.80		0.83			

C4: Recreation	A1	0.40	10	0.50	12	0.40	15	0.43	12.3	0.07	2.1
	A2	0.40		0.80		0.60		0.60			
	A3	0.70		0.60		0.70		0.67			
	A4	0.70		0.50		0.60		0.60			
C5: Water quality	A1	0.30	15	0.30	20	0.30	15	0.30	16.7	0.03	2.4
	A2	0.40		0.60		0.40		0.47			
	A3	0.50		0.50		0.60		0.53			
	A4	0.80		0.80		0.80		0.80			
C6: Agricultural use of the floodplain	A1	0.80	10	0.70	6	0.60	5	0.70	7.0	0.06	2.2
	A2	0.70		0.50		0.40		0.53			
	A3	0.30		0.30		0.35		0.32			
	A4	0.10		0.10		0.20		0.13			
C7: Implementation costs	A1	0.90	11	1.00	4	1.00	3	0.97	6.0	0.05	3.6
	A2	0.70		0.50		0.80		0.67			
	A3	0.40		0.40		0.40		0.40			
	A4	0.10		0.10		0.20		0.13			
C8: Effort of decision-making	A1	1.00	6	0.80	5	0.80	7	0.87	6.0	0.06	0.8
	A2	0.60		0.50		0.70		0.60			
	A3	0.40		0.50		0.45		0.45			
	A4	0.10		0.20		0.20		0.17			
C9: Feasibility	A1	0.50	8	0.50	8	0.50	20	0.50	12.0	0.07	5.7
	A2	0.70		0.40		0.60		0.57			
	A3	0.70		0.40		0.60		0.57			
	A4	0.50		0.30		0.40		0.40			

In terms of criteria weighting, the groups tend to give the highest priority to biodiversity and water quality. The criteria on implementation hurdles were often weighted rather low. There is little variation in weights between the groups. One exception is the weighting of Group Blue in the feasibility criterion.

Table 6: Elicited preference rankings of the groups for the river development options (A0 - A3) based on the overall score per alternative.

		Group Green (P2, P3, P5, P9)	Group Yellow (P4, P7, P10, P11)	Group Blue (P1, P6, P8)
Ranking I (based on equal weights)	A1	**0.556**	**0.556**	0.528
	A2	0.544	0.522	**0.544**
	A3	0.550	0.467	**0.544**
	A4	0.517	0.417	0.444
Ranking II (based on individual weights)	A1	0.504	0.462	0.446
	A2	0.529	0.528	0.528
	A3	0.564	0.518	**0.591**
	A4	**0.572**	**0.569**	0.520

The WLA model indicates that the alternative with major NBS interventions (A4) is the highest ranked option for river development of the Group Green and Group Yellow (Table 6). However, when assuming that all criteria should be equally important, no NBS interventions (A1) seem to be the preferred alternative of Group Green and Group Yellow. For Group Blue, the alternative with medium NBS interventions (A3) is the best rated, while with equal weighting, the preference order identified is less clear.

5. Discussion and conclusion

This study used a participatory MCE methodology to assist agency representatives to deliberate different river development options with varying levels of NBS interventions. This approach provided insights into how different administrative actors evaluate the performance of such nature-based options and weight the relative importance of selected implementation criteria.

The participants of the current MCE, both individually and collectively in small groups, expressed relative confidence that the greater the NBS interventions of the alternatives in the river segment, the more positive the performance of the alternatives with respect to ecological implementation goals (biodiversity and water quality). This result may have been expected, as it was anticipated that more ecosystem processes would be utilized, but also supported, with increasing levels of NBS interventions. It is consistent with empirical evaluations of the outcomes of river restoration projects, indicating that, in most cases, restoration improves ecological conditions (Lu et al., 2019). However, whether NBS interventions successfully improve ecological processes in riverine landscapes should not be a rule of thumb. The ecological outcome of a river restoration depends on a number of factors, e.g., the design or type of intervention, the size of the project and river basin, land-use characteristics, and stakeholder interests (Muhar et al., 2016; Palmer et al., 2014). Therefore, the ecological performance of NBS interventions should be assessed on a case-by-case basis using agreed-upon evaluation criteria and measurable indicators of ecological integrity to advance the understanding of trade-offs between the ecological benefits of restoring ecosystem processes and competing human demands for the goods and services provided by rivers (Beechie et al., 2010; Palmer et al., 2005).

Furthermore, the participants of the MCE generally expected that the increasing level of NBS interventions would have a negative impact on implementation costs and decision-making effort. Large improvements in the ecological performance of the considered river segment were more likely to be associated with high cost and effort. It appears that the alternative with larger NBS interventions was perceived to be less cost-effective than the alternatives with medium or smaller NBS interventions. Other studies also reported that NBS interventions are perceived to be costly (Liquete et al., 2016; Sarabi et al., 2020). Surprisingly, many individual participants as well as the small groups ranked the importance of implementation costs and decision-making effort rather low compared to the other implementation criteria. This includes participants in clusters 1 to 3 (Fig. 3), that mostly prioritized biodiversity and water quality, and in some cases other ecosystem services (flood control and recreation). One possible explanation might be that no cap on public spending was imposed and therefore participants did not have to decide between options for spending a limited amount of available funding. But it may also be a further evidence that administrative costs and investments required to plan such NBS interventions in rivers are not adequately reflected in strategic river basin planning (Graversgaard et al., 2017). The focus of most participants was rather on satisfying the (ecological) implementation goals as best as possible (maximizing the NBS criterion challenge-orientation) and, to some extent, on the prospect that a river development option can be realized within institutional constraints and with public approval. Consequently, as evident in the calculated rankings of alternatives, these participants, and small groups respectively show a potential preference for the alternatives with major (A4) or medium (A3) NBS interventions. While A4 is expected to deliver higher performance gains in ecosystem services, A3 is perceived as the more feasible river development option and appears to be preferred by participants in cluster 3 who value ecological improvements but also consider, at least to some degree, implementation costs or feasibility in terms of institutional capacity and public acceptance. Accordingly, there seems to be a trade-off among participants between the promotion of biodiversity and other ecosystem services and the practical viability of NBS interventions.

The drawn decision tree model further underlines these findings. It suggests that the potential preference of the participants for varying levels of NBS interventions for river development was based on certain considerations. The alternative with major NBS interventions (A4) tends to be preferred by those (administrators) who would be considered to have a strong ecological or conservation orientation, as they expected high performance scores in biodiversity and water quality, gave (very) high weight to these criteria, and tended to pay less attention to implementation hurdles. The more a participant focused on potential hurdles such as cost and decision burden, as well as (land) uses that potentially conflict with NBS interventions - e.g., floodplain agricultural use and boating - the more likely this resulted in an MCE-guided preference for alternatives with lower NBS interventions (A1 or A2; this accounts for participants in cluster 4). Likewise, our equal weighting of all criteria in the WLA model shows that when no (clear) priorities are set for the ecosystem performance criteria, most participants judge A1 or A2 best. Following Clewell and Aronson (2006), this suggests that the participants of the current MCE tended to base their considerations about the river development options on either biotic (enhance biodiversity), pragmatic (practice-oriented), or technocratic (satisfy specific institutional missions and mandates) reasoning.

Several limitations need to be noted regarding the present study. The findings and implications of this participatory MCE study need to be critically viewed in terms of the influence of contextual conditions, actor constellations, and the design of our MCE method (Langhans and Lienert, 2016). Clearly, a different setting, such as focusing on a different study area, involving other actors, or a different policy context, such as the occurrence of a major flood event as is currently occurring in Germany, may have a significant impact on participants' responses. The sample is small and characterized by high heterogeneity, making it difficult to identify patterns among the stated performance scores and weights for explaining the rankings of the alternatives. In addition, participants were not asked directly about their preference for a particular alternative, but instead used the rankings of the alternative calculated from the WLA model as information for a likely preference order. The WLA model disregards the consideration of incommensurable values (Munda, 2008), which means that better performance scores on one criterion can offset poor performance scores on another criterion. It may therefore be difficult for a participant to assign a higher weight to one criterion by lowering the weight of another criterion, as it requires careful consideration of the relative importance of each criterion. Furthermore, it was noticed that the deliberation phase in the workshop was very short. The lack of time to reflect on performance scores and weights may be one reason why the MCE outcomes of the small groups slightly differ with individual MCE outcomes.

The current findings raise intriguing questions about the planning and decision-making of NBS interventions in river landscapes:

1) *Which of the river development options considered in the current case study meets the criteria for a NBS, i.e., challenge-orientation, ecosystem process utilization and practical viability?* Looking at the performance scores given by the participants, none of the alternatives clearly meet all NBS criteria. The alternative with major NBS interventions (A4) seems to have a positive impact on most implementation goals (more challenge-orientated), but its practical viability regarding the criteria implementation costs, decision-making effort and feasibility is judged negatively. The other alternatives appear to address fewer goals (less challenge-oriented), i.e., their performance either remained unchanged or was scored negatively, but their implementability was scored more positively (more practical viable). It therefore implies that not all river restoration efforts are necessarily nature-based solutions.

2) *Which of the performances of the river development options should be decisive?* All participants were relatively certain that NBS interventions would have a positive impact on biodiversity and water quality and weighted these criteria relatively high. Nonetheless, it can be stated that biodiversity and water quality were not the deciding criteria in this case study, but rather the performance judgment and weighting of the criteria of boating, agricultural use of the floodplain, and feasibility. Participants appeared to have differing views on these criteria, which consequently affected the rankings. The evaluators would have needed more empirical information and methodological support to assess these criteria performances more reliably. For example, considering the case of flood protection, there is often uncertainty if NBS provide adequate water flow storage or retention capacities when compared to grey infrastructure solutions. To address these uncertainties, additional evaluation criteria and adequate indicators may need to be developed (Nadim and Tacnet, 2021). It also suggests that the alternative that best enhances the ecological performance and maximizes synergies between non-ecological goals has the greatest potential to be preferred as an NBS. However, there is also a need to discuss whether and how the performance of the NBS criteria should be weighted. Following Munda (2008, p.82), equal weighting can be justified from both a theoretical and empirical perspective. Theoretically, because there is a priori no reason why the NBS criteria should have different priorities - akin to the sustainability dimensions. Pragmatically, because in a multidisciplinary setting such as NBS planning in riverine landscapes, assuming equal weighting is equivalent to giving equal importance to the different disciplines involved in the decision-making process, which may reduce internal conflicts. However, according to Catrinu-Renström et al. (2013, p. 48), "[equal weighting] violates the theory of MCDA because impact ranges should be taken into account in determining weights. Equal weights can lead to situations where small disadvantages are weighted as much as large benefits."

3) *Should (administrative) planners prioritize specific NBS criteria, or should stakeholders legitimize priorities through a deliberative process?* The current MCE cannot give a direct answer to this question, but it shows the meaningfulness of actively involving different stakeholders in the process of performance evaluation and weighting and giving them the opportunity to deliberate on evaluation results. The deliberation on individual performance scores and weightings in the small groups showed that, in the end, the groups tended to choose similar overall scores and weights, and that that deviations on most criteria (especially biodiversity) decreased compared to individual judgments.

Unfortunately, active participation and deliberations in the (multi-criteria) evaluation of interventions in German river basin planning is not a common practice (Brillinger et al., 2020).

Overall, the present study contributes to the understanding of how individuals and groups of administrators make judgments about different NBS interventions for river development. It provides a starting point for future MCE studies on how to evaluate actions that may qualify as NBS in a participatory and deliberative manner. Further participatory and deliberative MCE studies about nature-based river development that better operationalize and include criteria for a NBS and try different decision and aggregation rules should be conducted.

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References

Albert, C., Brillinger, M., Guerrero, P., Gottwald, S., Henze, J., Schmidt, S., Ott, E., Schröter, B., 2021a. Planning nature-based solutions: Principles, steps, and insights. Ambio 50, 1446–1461. https://doi.org/10.1007/s13280-020-01365-1

Albert, C., Hack, J., Schmidt, S., Schröter, B., 2021b. Planning and governing nature-based solutions in river landscapes: Concepts, cases, and insights. Ambio 50, 1405–1413. https://doi.org/10.1007/s13280-021-01569-z

Albert, C., Schröter, B., Haase, D., Brillinger, M., Henze, J., Herrmann, S., Gottwald, S., Guerrero, P., Nicolas, C., Matzdorf, B., 2019. Addressing societal challenges through nature-based solutions: How can landscape planning and governance research contribute? Landsc. Urban Plan. 182, 12–21. https://doi.org/10.1016/j.landurbplan.2018.10.003

Allain, S., Plumecocq, G., Leenhardt, D., 2017. How Do Multi-criteria Assessments Address Landscape-level Problems? A Review of Studies and Practices. Ecol. Econ. 136, 282–295. https://doi.org/10.1016/j.ecolecon.2017.02.011

Beach, D., Pedersen, R., 2019. Process-Tracing Methods. University of Michigan Press, Ann Arbor, MI. https://doi.org/10.3998/mpub.10072208

Beechie, T.J., Sear, D.A., Olden, J.D., Pess, G.R., Buffington, J.M., Moir, H., Roni, P., Pollock, M.M., 2010. Process-based principles for restoring river ecosystems. Bioscience 60, 209–222. https://doi.org/10.1525/bio.2010.60.3.7

Brillinger, M., Dehnhardt, A., Schwarze, R., Albert, C., 2020. Exploring the uptake of nature-based measures in flood risk management: Evidence from German federal states. Environ. Sci. Policy 110, 14–23. https://doi.org/10.1016/j.envsci.2020.05.008

Brillinger, M., Henze, J., Albert, C., Schwarze, R., 2021. Integrating nature-based solutions in flood risk management plans: A matter of individual beliefs? Sci. Total Environ. 795, 148896. https://doi.org/10.1016/j.scitotenv.2021.148896

Catrinu-Renström, M.D., Barton, D.N., Bakken, T.H., Marttunen, M., Mochet, A.M., May, R., Hanssen, F., 2013. Multi-criteria analysis applied to environmental impacts of hydropower and water resources regulation projects.

Clewell, A.F., Aronson, J., 2006. Motivations for the restoration of ecosystems. Conserv. Biol. 20, 420–428. https://doi.org/10.1111/j.1523-1739.2006.00340.x

Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S., 2016. Nature-based Solutions to address global societal challenges. Gland, Switzerland.

Collier, D., 2011. Understanding process tracing. PS - Polit. Sci. Polit. 44, 823–830. https://doi.org/10.1017/S1049096511001429

Croeser, T., Garrard, G., Sharma, R., Ossola, A., Bekessy, S., 2021. Choosing the right nature-based solutions to meet diverse urban challenges. Urban For. Urban Green. 65, 127337. https://doi.org/10.1016/j.ufug.2021.127337

De Brito, M.M., Evers, M., 2016. Multi-criteria decision-making for flood risk management: A survey of the current state of the art. Nat. Hazards Earth Syst. Sci. 16, 1019–1033. https://doi.org/10.5194/nhess-16-1019-2016

de Castro-Pardo, M., Fernández Martínez, P., Pérez Zabaleta, A., Azevedo, J.C., 2021. Dealing with Water Conflicts: A Comprehensive Review of MCDM Approaches to Manage Freshwater Ecosystem Services. Land 10, 469. https://doi.org/10.3390/land10050469

ECA (European Court of Auditors), 2018. Floods Directive: progress in improve and implementation need to assessing risks, while planning, Special Report.

EEA (European Environment Agency), 2018. European water. Assessment of status and pressures 2018. https://doi.org/10.2800/303664

Eggermont, H., Balian, E., Azevedo, J.M.N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P., Reuter, K., Smith, M., van Ham, C., Weisser, W.W., Le Roux, X., 2015. Nature-based Solutions: New Influence for Environmental Management and Research in Europe. GAIA - Ecol. Perspect. Sci. Soc. 24, 243–248. https://doi.org/10.14512/gaia.24.4.9

Ekka, A., Pande, S., Jiang, Y., Zaag, P. van der, 2020. Anthropogenic modifications and river ecosystem services: A landscape perspective. Water (Switzerland) 12, 1–21. https://doi.org/10.3390/w12102706

Estévez, R.A., Gelcich, S., 2015. Participative multi-criteria decision analysis in marine management and conservation: Research progress and the challenge of integrating value judgments and uncertainty. Mar. Policy 61, 1–7. https://doi.org/10.1016/j.marpol.2015.06.022

European Commission, 2015. Towards an EU Research and Innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities. Final Report of the Horizon 2020 Expert Group. 35. Directorate-General for Research and Innovation, European Commission, Brussels, Belgium.

Everitt, B., Hothorn, T., 2011. An Introduction to applied multivariate analysis.

Garmendia, E., Gamboa, G., 2012. Weighting social preferences in participatory multi-criteria evaluations: A case study on sustainable natural resource management. Ecol. Econ. 84, 110–120. https://doi.org/10.1016/j.ecolecon.2012.09.004

Gómez Martín, E., Máñez Costa, M., Schwerdtner Máñez, K., 2020. An operationalized classification of Nature Based Solutions for water-related hazards: From theory to practice. Ecol. Econ. 167, 106460. https://doi.org/10.1016/j.ecolecon.2019.106460

Govindaraju, R.S., Rao, A.R., 2000. Artificial Neural Networks in Hydrology, Water Science and Technology Library. Springer Netherlands, Dordrecht. https://doi.org/10.1007/978-94-015-9341-0

Graversgaard, M., Jacobsen, B.H., Kjeldsen, C., Dalgaard, T., 2017. Stakeholder engagement and knowledge co-creation in water planning: Can public participation increase cost-effectiveness? Water (Switzerland) 9, 1–29. https://doi.org/10.3390/w9030191

Hajkowicz, S., Collins, K., 2007. A review of multiple criteria analysis for water resource planning and management. Water Resour. Manag. 21, 1553–1566. https://doi.org/10.1007/s11269-006-9112-5

Hastie, T., Tibshirani, R., Friedman, J., 2009. The Elements of Statistical Learning. Data Mining, Inference, and Prediction, Second Edi. ed, Journal of the Royal Statistical Society, Springer Series in Statistics. Springer New York, New York, NY. https://doi.org/10.1007/b94608

Husson, F., Josse, J., Lê, S., Mazet, J., 2017. FactoMineR: multivariate exploratory data analysis and data mining. R package version 1.41.

Jolliffe, I.T., 2002. Principal Component Analysis, Springer Series in Statistics. Springer-Verlag, New York. https://doi.org/10.1007/b98835

Koenzen, U., Günther-Diringer, D., 2021. Auenzustandsbericht 2021, Flussauen in Deutschland. https://doi.org/10.19217/brs211

Langemeyer, J., Palomo, I., Baraibar, S., Gómez-Baggethun, E., 2018. Participatory multi-criteria decision aid: Operationalizing an integrated assessment of ecosystem services. Ecosyst. Serv. 30, 49–60. https://doi.org/10.1016/j.ecoser.2018.01.012

Langhans, S.D., Lienert, J., 2016. Four common simplifications of multi-criteria decision analysis do not hold for river rehabilitation. PLoS One 11, 1–27. https://doi.org/10.1371/journal.pone.0150695

Lê, S., Josse, J., Husson, F., 2008. FactoMineR: An R Package for Multivariate Analysis. J. Stat. Softw. 25, 1–18.

Lennox, J., Proctor, W., Russell, S., 2011. Structuring stakeholder participation in New Zealand's water resource governance. Ecol. Econ. 70, 1381–1394. https://doi.org/10.1016/j.ecolecon.2011.02.015

Liquete, C., Udias, A., Conte, G., Grizzetti, B., Masi, F., 2016. Integrated valuation of a nature-based solution for water pollution control . Highlighting hidden bene fi ts. Ecosyst. Serv. 1–10. https://doi.org/10.1016/j.ecoser.2016.09.011

Loos, J.R., Rogers, S.H., 2016. Understanding stakeholder preferences for flood adaptation alternatives with natural capital implications. Ecol. Soc. 21. https://doi.org/10.5751/ES-08680-210332

Lu, W., Arias Font, R., Cheng, S., Wang, J., Kollmann, J., 2019. Assessing the context and ecological effects of river restoration – A meta-analysis. Ecol. Eng. 136, 30–37. https://doi.org/10.1016/j.ecoleng.2019.06.004

Messner, F., Zwirner, O., Karkuschke, M., 2006. Participation in multi-criteria decision support for the resolution of a water allocation problem in the Spree River basin. Land use policy 23, 63–75. https://doi.org/10.1016/j.landusepol.2004.08.008

Moss, T., 2007. Institutional drivers and constraints of floodplain restoration in Europe. Int. J. River Basin Manag. 5, 121–130. https://doi.org/10.1080/15715124.2007.9635312

Muhar, S., Januschke, K., Kail, J., Poppe, M., Schmutz, S., Hering, D., Buijse, A.D., 2016. Evaluating good-practice cases for river restoration across Europe: context, methodological framework, selected results and recommendations. Hydrobiologia 769, 3–19. https://doi.org/10.1007/s10750-016-2652-7

Munda, G., 2008. Social multi-criteria evaluation for a sustainable economy. https://doi.org/10.1007/978-3-540-73703-2

Nadim, F., Tacnet, J.-M., 2021. NBS for disaster risk reduction, in: Dumitru, A., Wendling, L. (Eds.), Evaluating the Impact of Nature-Based Solutions. A Handbook for Practitioners. European Commission, Brussels, pp. 241–272.

Nelson, D.R., Bledsoe, B.P., Ferreira, S., Nibbelink, N.P., 2020. Challenges to realizing the potential of nature-based solutions. Curr. Opin. Environ. Sustain. 45, 49–55. https://doi.org/10.1016/j.cosust.2020.09.001

Nesshöver, C., Assmuth, T., Irvine, K.N., Rusch, G.M., Waylen, K.A., Delbaere, B., Haase, D., Jones-Walters, L., Keune, H., Kovacs, E., Krauze, K., Külvik, M., Rey, F., van Dijk, J., Vistad, O.I., Wilkinson, M.E., Wittmer, H., 2016. The science, policy and practice of nature-based solutions: An interdisciplinary perspective. Sci. Total Environ. 579, 1215–1227. https://doi.org/10.1016/j.scitotenv.2016.11.106

NWRM, 2015. Catalogue of natural water retention measures [WWW Document]. URL http://nwrm.eu/measures-catalogue

Palmer, M.A., Bernhardt, E.S., Allan, J.D., Lake, P.S., Alexander, G., Brooks, S., Carr, J., Clayton, S., Dahm, C.N., Follstad Shah, J., Galat, D.L., Loss, S.G., Goodwin, P., Hart, D.D., Hassett, B., Jenkinson, R., Kondolf, G.M., Lave, R., Meyer, J.L., O'Donnell, T.K., Pagano, L., Sudduth, E., 2005. Standards for ecologically successful river restoration. J. Appl. Ecol. 42, 208–217. https://doi.org/10.1111/j.1365-2664.2005.01004.x

Palmer, M.A., Hondula, K.L., Koch, B.J., 2014. Ecological restoration of streams and rivers: Shifting strategies and shifting goals. Annu. Rev. Ecol. Evol. Syst. 45, 247–269. https://doi.org/10.1146/annurev-ecolsys-120213-091935

Proctor, W., Drechsler, M., 2003. Deliberative multi-criteria evaluation: a case study of recreation and tourism options in Victoria, Australia 1–22.

Ruangpan, L., Vojinovic, Z., Plavšić, J., Doong, D.J., Bahlmann, T., Alves, A., Tseng, L.H., Randelović, A., Todorović, A., Kocic, Z., Beljinac, V., Wu, M.H., Lo, W.C., Perez-Lapeña, B., Franca, M.J., 2020. Incorporating stakeholders' preferences into a multi-criteria framework for planning large-scale Nature-Based Solutions. Ambio. https://doi.org/10.1007/s13280-020-01419-4

Santoro, S., Pluchinotta, I., Pagano, A., Pengal, P., Cokan, B., Giordano, R., 2019. Assessing stakeholders' risk perception to promote Nature Based Solutions as flood protection strategies: The case of the Glinščica river (Slovenia). Sci. Total Environ. 655, 188–201. https://doi.org/10.1016/j.scitotenv.2018.11.116

Sarabi, S., Han, Q., Romme, A.G.L., de Vries, B., Valkenburg, R., den Ouden, E., 2020. Uptake and implementation of Nature-Based Solutions: An analysis of barriers using Interpretive Structural Modeling. J. Environ. Manage. 270, 110749. https://doi.org/10.1016/j.jenvman.2020.110749

Schröter, B., Hack, J., Hüesker, F., Kuhlicke, C., Albert, C., 2022. Beyond Demonstrators—tackling fundamental problems in amplifying nature-based solutions for the post-COVID-19 world. npj Urban Sustain. 2, 4. https://doi.org/10.1038/s42949-022-00047-z

Seddon, N., Chausson, A., Berry, P., Girardin, C.A.J.J., Smith, A., Turner, B., 2020. Understanding the value and limits of nature-based solutions to climate change and other global challenges. Philos. Trans. R. Soc. B Biol. Sci. 375, 20190120. https://doi.org/10.1098/rstb.2019.0120

Stagl, S., 2006. Multicriteria evaluation and public participation: the case of UK energy policy. Land use policy 23, 53–62. https://doi.org/10.1016/J.LANDUSEPOL.2004.08.007

Therneau, T., Atkinson, B., 2019. rpart: Recursive Partitioning and Regression Trees. R package version 4.1-15.

Zarfl, C., Lehner, B., 2020. European rivers are fragmented by many more barriers than had been recorded. Nature 588, 395–396. https://doi.org/10.1038/d41586-020-03440-9