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Linking ecosystem services and measures in river and floodplain management

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ABSTRACT

The management of rivers and floodplains is subject to multiple legal frameworks. For this reason, methods that allow a comparison of different management options are needed. Here, we apply both a literature and an expert-based approach to present an utilisable and transparent matrix approach for Central Europe, linking an array of 17 management measures with the provision of 23 ecosystem services (ESSs). In the overall matrix, 44% of the links were found to be positive or highly positive and 11% were negative or highly negative, while the other links were characterised as ambiguous or as having no effect. Overall, the effect spectra of management measures on various ESSs often indicated reduced provisioning ESSs, in particular those related to agriculture, while regulating and cultural ESSs have increased. Habitat restoration, floodplain restoration and flood risk reduction on agricultural land were the management measures that showed the most positive effects on ESSs, followed by dyke relocation. Besides the evaluation of such measures, this comprehensive approach helped to reveal knowledge gaps regarding the effects of management measures on the ESSs dealing with nutrient retention, and cultural ESSs. The matrix allows an integrative evaluation of the multifunctionality and efficiency of common management measures.

1. Introduction

For centuries, humans have intensively modified and used rivers and floodplains (Carpenter et al. 2011), often leading to a decreased ecological status and a loss of the floodplain character (BMU and BfN, 2009). Multiple legal frameworks have been developed to reduce flood risk, improve ecological status and conserve habitats; nowadays, such frameworks significantly influence the management of rivers and floodplains. Within the European Union, these include the EU Water Framework Directive (WFD), the EU Flood Risks Directive (FRD) and the EU Habitats Directive (HD) (Tockner et al. 2010; EEA 2016). Additionally, the EU’s Common Agricultural Policy (CAP) and the EU Water Convention (Council of Europe, ETS No.176) have affected the management of rivers and floodplains (Hauck et al. 2014; Seardo 2015). Of these directives, the WFD and the HD focus on environmental goals (EEA 2016). The goal of the WFD is to improve the ecological status of aquatic ecosystems by fostering the implementation of measures that aim to reduce human pressures on aquatic ecosystems (Jähnig et al. 2009; Grizzetti et al. 2016). The goal of the HD is to protect rare, threatened or endemic animal and plant species as well as habitats (Council Directive 92/43/EEC). In contrast, the FRD focuses on the reduction of flood risk to human welfare, which implies many trade-offs with the WFD (EEA 2016, 2017). Multiple synergies between mentioned policies exist; however, integrated approaches for their implementation are largely missing (Bouwma et al. 2018). This underlines the need for developing an integrated approach to water management, flood risk management and nature conservation for rivers and floodplains (Linnenweber and Mirbach 2011; Jessel 2014; EEA 2016). In light of this, the ecosystem service (ESS) approach has been proposed as a tool to represent the various ways humans benefit from river and floodplain ecosystems and thus develop a comparison of management measures based on the functioning of the riverine landscape (Pusch 2016; Podschun et al. 2018a).

The EU Biodiversity Strategy (EC 2011) explicitly mentions ESSs as prerequisites for the preservation of biodiversity, in Action 5 (‘Map and assess the state and economic value of ecosystems and their services in the entire EU territory; promote the recognition of the economic value into accounting and reporting systems across Europe’), Action 6 (‘Restore ecosystems, maintain their services and promote the use of green infrastructure’) and Action 7 (‘Assess the impact of EU funds on biodiversity and investigate the opportunity of a compensation or offsetting scheme to ensure that there is no net loss of biodiversity and ecosystem services’). Although the ESS concept is not mentioned explicitly in the WFD, it...
has the potential to be used in achieving the WFD objectives (Vlachopoulou et al. 2014; Grizzetti et al. 2016), because it provides an innovative approach to evaluating freshwater resources (Harrison-Atlas et al. 2016). The evaluation of ESSs may support the planning of management measures (MMs) towards optimised integrated management (e.g. Daily et al. 2009; Groot et al. 2010; TEEB 2010; Wang et al. 2013; Fürst et al. 2017). This means that a single MM may influence several ESSs, several MMs may influence a single ESS, and significant trade-offs between ESSs also exist (Rouquette et al. 2011; Goldstein et al. 2012; Zheng et al. 2016). In practice, the ESS concept can on the one hand help decision-makers to leverage synergies and manage trade-offs between ESSs (Kistenkas and Bouwma 2018) and on the other hand bridge the communication gap between science and decision-makers (Daily et al. 2009; Chan et al. 2012; Harrison-Atlas et al. 2016). However, policy impacts on ESSs have barely been studied up to now (Hauck et al. 2014), and studies in the context of rivers and floodplains are often limited to single measures and a few ESSs (Hanna et al. 2018). Against this background, the objective of our study was to develop a comprehensive matrix linking MMs implemented under the WFD and FRD to the provision of a wide range of ESSs in rivers and floodplains.

Initially, the matrix approach was proposed as a simple, straightforward look-up table linking ESSs and land cover types to enable a quick initial assessment, even in data-scarce regions (Burkhard et al. 2009). Such expert-based assessments are widespread in ESS research in the case of insufficient data (Seppelt et al. 2011; Schindler et al. 2014; Campagne et al. 2017). The matrix approach also has proven to be a valuable method for providing an overview on the effects of interventions on multiple ESSs, e.g. in a floodplain context (Schindler et al. 2014). It enables researchers to depict the consequences of MMs even for ESSs that are often overlooked, such as cultural ESSs (Hauck et al. 2014; Kistenkas and Bouwma 2018) and allows for a more holistic understanding of the effects of MMs, especially by conservation managers (Eastwood et al. 2016). In light of the rapidly growing number of publications on ESS, reviews that summarise the scientific knowledge on the links between ESSs and MMs can give important insights for policymakers, such as those revealed by the example of the CAP (Hauck et al. 2014).

With the aim of elaborating a comprehensive overview on the potential impact of river and floodplain management measures on ESSs provision, we developed a matrix approach, combining a scientific literature review and an expert-based approach. This proceeded in four steps. (1) The matrix was set up to contain 23 ESSs, including provisioning, regulating and cultural ESSs that are relevant for rivers and floodplains (Podschun et al. 2018b) and 17 MMs. In contrast to the overview study conducted by Schindler et al. (2014), we examined measures from the LAWA-BLANO catalogue (LAWA 2015) in order to improve usability for practitioners at local to regional levels. The LAWA-BLANO catalogue collates and standardises the MMs commonly implemented in Germany at the federal level, including MMs related to the WFD, the FRD or the Marine Strategy Framework Directive (Rieth et al. 2017). (2) The links were evaluated in a literature review. (3) Experts were asked to evaluate each link. (4) The results from both approaches were coupled with each other to derive the final matrix. Taking such an integrative approach enabled us to (a) provide a comprehensive overview and identify gaps in research, (b) show potential unintended positive or negative effects of MMs commonly implemented under the WFD and the FRD regarding effects on rivers and floodplains, (c) identify MMs that influence a particularly high number of ESSs in a positive manner, or that produce a low number of trade-offs. With this, this paper aims to provide a basis to inform decision-makers using the ESS approach fostering the cross-sectoral management of rivers and floodplains.

2. Methods

2.1. Setting up the matrix – ecosystem services and management measures

The European Union has identified 25 ‘Key Type Measures’ which it uses in the context of reports for the EU Commission. These key type measures refer to the WFD and the FRD, and thus are primarily relevant for European-scale measures. The German LAWA-BLANO catalogue (LAWA 2015) documents MMs related to implementation in Germany, which might differ from other European countries. In the LAWA-BLANO catalogue, the numbers 1 to 96 refer to MMs under the WFD, and numbers 301–318 to MMs under the FRD. This study is focused on MMs dealing with environmental restoration. MMs related to educational or political purposes (e.g. water-pricing policies or advisory measures for agriculture) as well as MMs developed for other EU regions were excluded. Ultimately, 17 MM bundles were included in the matrix (Table 1).

The list of 23 ESSs (see Table 3) was adopted from Podschun et al. (2018b), who identified which ESSs were relevant for rivers and floodplains in Germany based on the Common International Classification of Ecosystem Services (CICES version 4.3 (Haines-Young and Potschin 2013)). ESSs related to terrestrial, semiaquatic and aquatic ecosystems were combined in this list (e.g. wild animals and wild fish); this helps foster integrative assessment and management approaches for river floodplain systems (Podschun et al. 2018b). This
Table 1. The 17 management measures (MM). In the first column is the abbreviation of the MM and the related number of the LAWA-BLANO catalogue MM in brackets. In the second column is the chosen name for the measure bundle and in the third column examples of specific measures taken from the LAWA-BLANO catalogue.

| Abbreviation | Management Measures | Examples (LAWA-BLANO catalogue) |
|--------------|---------------------|---------------------------------|
| MM 1 (1–26, 38–40) | Construction or upgrades of wastewater treatment plants (WWTPs) | New construction, technical upgrading and increase in capacity and efficiency of WWTPs; pit water purification, decontaminating polluted sites, new construction of cooling systems, decoupling of sealed areas from the sewer system. |
| MM 2 (27–32, 41–42) | Reduction of pollution from agriculture | Compliance with the “good agricultural practice”, conservation soil tillage, erosion minimization, hillside area greening, intercropping, change to organic farming, change of management of drained areas, reduction of pesticides. |
| MM 3 (28) | Establishment of buffer zones | Creation, extension or extensification of linear riparian buffer strips. |
| MM 4 (34, 37) | Counteraction of acidification | Liming, conversion to near-natural forests. |
| MM 5 (45–60) | Reduction of water abstractions | Reduction of cooling water, upgrading of hydropower plant turbines, water-efficient irrigation, reduction of water abstractions for navigation and ponds, dismantling of wells, restructuring the water supply system, compensation of abstractions through additional seepage. |
| MM 6 (61–64) | Restoration of the natural flow regime | Reestablishment or securing of minimal flow at transverse structures, reduction of hydropoeaking effects and reduction of backwater areas. |
| MM 7 (65–66, 301–305, 311–313) | Floodplain restoration | Rewatering and restoration of wetlands, conservation of mires, near-natural widening of the water body, reforestation, promotion of near-natural floodplain development, reduction of sealing, rain seepage facilities, green roofs, restoration of former inundation areas, preserving retention areas, conversion of arable land to permanent pasture, demolishing of flood-sensitive facilities. |
| MM 8 (314) | Dyke relocation, slotting or dismantling | Dyke relocation, slotting or dismantling. |
| MM 9 (68, 69) | Restoration of longitudinal connectivity | Creation of passable facilities (bypass channels, river bottom glides, fish ladders), demolishing of weirs or culverts. |
| MM 10 (70–87) | Habitat improvement | Removal of bed or bank consolidation, introduction of large wood or stones, creation of gravel spawning grounds, allow eroding of the shores, re-meandering, reactivate primary floodplains, connecting tributaries or cut-off meanders, fish protection, sediment management, creation of shallow water zones and typical bank structures, de-sludging. |
| MM 11 (77) | Improvement of bedload budget and sediment management | Artificial addition of river compliant bedrock, restoration of some part of the rivers gravel load below the dam, demolishing or creating of sediment traps, installation of gravel pipes at transverse structures. |
| MM 12 (88–92) | Stocking | Initial stocking, measures to reduce the burdens of fishery exploitation (e.g. meet fisheries principles). |
| MM 13 (93) | Prevention of adverse impacts of drainage | Closure or dismantling of drains, isolation of ditches, lengthening of the river to enhance water retention. |
| MM 14 (94) | Prevention or control of the adverse impacts of invasive species | Promotion of autochthonous plant communities, combat of ecosystem damaging neobiotia, protection of native species. |
| MM 15 (95, 96) | Prevention or control of the adverse impacts of recreation | Prohibitions of navigating waters, control of visitor movements, prohibitions of camping or campfires, restoration of lakes that have been used for bathing (e.g. as a place for aquatic nutrient removal). |
| MM 16 (310) | Flood risk reduction on agricultural land | Conservation soil tillage, intercropping, near-natural forestry, afforestation of alluvial forest. |
| MM 17 (315–318) | Flood retention areas and dams | New construction, maintenance and restoration of retention areas, polders, reservoirs and dams, dyked area drainage. |

ESS list is suitable for various types of floodplains in Central Europe, from lowland rivers to mountainous areas. However, the matrix has been optimised for Germany; the ESS classifications should correspond to local characteristics and the cultural context. The literature review was focused on, but not limited to, European case studies in order to be able to complete the matrix as a whole.

The conceptual differentiation between 1) ESS provision/offered ESSs, referring to the capacity of the ecosystem to deliver the service; 2) ESSs actually used, also referred to as ‘ecosystem service flow’; and 3) ESS demand (Villamagna et al. 2013; Burkhard et al. 2014; Von Haaren et al. 2014; Albert et al. 2015) is also applicable to rivers and floodplains (Podschun et al. 2018b). We focused the matrix approach on ESS provision, yet it must be acknowledged that many studies fail to explicitly mention the aspect of the ESS concept being assessed (Hanna et al. 2018).

Due to their similarity, some of the ESSs selected for this study have been grouped together into ESSs related to water supply (‘surface and ground water for drinking’, ‘water for non-drinking purposes’); agriculture-based ESSs (‘cultivated crops’, ‘plant resources for agricultural use, fibres and other materials from plants for direct use or processing’, ‘plant-based resources’); mitigation of flows (‘flood and drought risk regulation’, ‘drainage capability’, ‘mass flow/sediment regulation’, ‘soil formation in floodplains’, ‘local temperature regulation/cooling’); and retention of nutrients (‘retention of organic C’, ‘retention of N’ and ‘retention of P’).

### 2.2. The literature-based approach

The first step was to conduct a literature review to search for reports and scientific papers for each link between a MM and the resulting change in an ESS. A number of search terms (both in English and in
German) were used in several search engines, including Science Direct, Web of Science, Primus Gateway of Humboldt University Berlin, as well as Google Scholar to cover grey literature. Search terms included i) the name of the MM and, alternatively, key terms of the examples listed in the LAWABLANO catalogue (see Table 1); ii) the names of the ESSs themselves, including alternative terms when applicable; iii) finally, when necessary, the terms ‘floodplain’, ‘river’, or ‘water’ etc. were added if the MM title alone was not restrictive enough. Geographic limitations were not included in the search terms. However, the articles’ titles, keywords and sometimes abstracts were checked for relevance for the European context with regard to species or habitats they assessed (thereby excluding, e.g. mangroves). The initial search time was 20 minutes in order to treat all of the 391 ESS/MM links equally, even if no relationship was expected. It can be assumed that widespread and recognised literature as well as practice-oriented studies were found within this timespan. Next, the research team reviewed the studies that came up, including a crosscheck of the relevance of referenced studies. In case of scarce literature, studies that only indirectly addressed the links were taken into consideration as well, such as documents describing the decrease of a certain pressure by a specific MM, even if the name of the ESS was not explicitly mentioned. This resulted in a total of 208 relevant publications (see overview per link between MM and ESS in the Online Appendix), and the research team categorised the results for each link as positive, negative or ambiguous (in cases of contrasting evidence) (see Table 2).

2.3. The expert-based approach

To validate and complement the literature review, we also took an expert-based approach in October 2017. The 17 experts represented universities, research institutes or landscape planning companies, and were familiar with the selected ESSs and MMs. The overall matrix comprised 609 fields, including developmental issues, while the present article focusing on management measures only considers 23 ESS and 17 MM, and thus a total of 391 matrix cells. To allow the experts to stay within a reasonable time frame (40 minutes) to fill in the overall matrix, this part of the research proceeded in two steps.

In the first step, three focus groups were formed including five to six experts with mixed expertise from different institutions. Each group had a poster of the matrix including all 17 MMs and nine (one group) or ten (two groups) ESSs and were asked to evaluate each link from highly positive to highly negative (see Table 2). Each expert could state their choice separately, but while filling in the matrix, they also had the opportunity to discuss within the group. Campagne et al. (2017) and Jacobs et al. (2014) proposed using confidence measures in ESS matrix assessments with experts. However, asking the experts for their individual confidence for each link would have increased the time needed to fill in the matrix substantially. Hence, we applied an alternative approach by examining the variation among the experts’ evaluations, (i.e. if they agreed or not on one common evaluation) and how many experts stated an opinion. Moreover, the experts were supervised while filling in the matrix, which provided an additional qualitative source of information about uncertainty.

The second step consisted of tallying and comparing the experts’ answers with the results from the literature-based approach. The matrix cells that the experts themselves disagreed about and/or that showed a discrepancy between the experts’ evaluations and the literature-based results were identified and marked. After that, all 17 experts met together to discuss these ‘controversial’ matrix links, giving

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**Table 2.** Explanation of the six valuation categories and the colour scale.

| Calculation value | Colour    | Description                                                                 |
|-------------------|-----------|-----------------------------------------------------------------------------|
| 2                 | dark blue | Highly positive effect.                                                     |
| 1                 | blue      | MM enhances ESS or has a positive effect.                                   |
| 0                 | green     | Positive as well as negative effects, unclear effect or effect differs according to environmental conditions. |
| -1                | orange    | MM reduces ESS or has a negative effect.                                    |
| -2                | red       | Highly negative effect.                                                    |
|                   | white     | No link between MM and ESS. This is used if applying an MM has no significant effect on the ESS under most conditions, although there can be several indirect effects, or effects that are only relevant for special cases under atypical conditions. |
|                   | grey      | Not assessed.                                                              |
all experts the chance to comment on the overall
matrix. In other words, the main focus was on the
controversial matrix links in order to understand the
context that led to a particular decision. The results
did not change in the second step, but more infor-
mation about the disagreements emerged.

Table 3. Matrix of links between management measures (MM) (see Table 1) and ecosystem services (ESS) of rivers and floodplains. For explanation of the colours see in the top left corner and Table 2. Matrix cells marked with an asterisk have a weak scientific certainty.

| Provisioning services | Management Measures |
|-----------------------|----------------------|
| Cultivated crops      | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 |
| Plant resources for agricultural use |            |
| Wild animals and fish |            |
| Surface water for drinking |            |
| Ground water for drinking |            |
| Fibers and other materials from plants for direct use or processing |            |
| Water for non-drinking purposes |            |
| Plant-based resources |            |

| Regulating services | Management Measures |
|---------------------|----------------------|
| Retention of organic C | * 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 |
| Retention of N |            |
| Retention of P |            |
| Retention of greenhouse gas emission / carbon sequestration |            |
| Flood risk regulation |            |
| Drought risk regulation |            |
| Drainage capability |            |
| Mass flow / Sediment regulation |            |
| Soil formation in floodplains |            |
| Local temperature regulation/Cooling |            |
| Maintaining habitats |            |

| Cultural services | Management Measures |
|-------------------|----------------------|
| Landscape aesthetics | * 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 |
| Natural and cultural heritage | * 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 |
| Unspecific interactions with riverine ecosystem | * 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 |
| Water-related activities | * 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 |
2.4. Elaboration of the final matrix

For 60% of the matrix cells, there was literature available about the link between an MM and an ESS, with an average of 2.3 (±4.7 SD, range 0–10) publications per cell. The expert-based assessment resulted in at least one expert evaluating all matrix cells but one, hence almost 100%. For each combination of MM and ESS, an average of 4.8 (±1.8 SD, range 0–6) experts provided an opinion. In two of the expert groups, all combinations were assessed by all experts, but in the third group (link to cultural ESSs and nutrient retention), only 3.4 (±2.1 SD, range 0–6) experts on average stated an answer.

The last step was to compare and compile the information about MM-ESS linkages obtained from literature review and from expert ratings within the final matrix according to the following rules: (1) If the available literature-based information was sparse and disputed, and the experts gave a less extreme ranking, a weaker link was entered into the matrix cell. This approach takes into account that the experts might be able to consider scale effects in their evaluation. (2) If no literature at all could be found, but the expert evaluation was comprehensible, it was adopted to the matrix. (3) If no literature could be found and the experts did not agree on one common evaluation but a) there was at least one expert who found the link to be ‘ambiguous’, this evaluation was chosen, or b) there was a clear majority for one evaluation, this evaluation was adopted, or c) if none of the previously mentioned cases applied, the matrix cell remained empty. In the cases of 3a and b, as well as in the case that no literature had been found and that fewer than three experts had entered an evaluation in the cell, the link was marked with an asterisk (Table 3) to indicate high uncertainty.

3. Results

3.1. Comparison of approaches

3.1.1. Provisioning services

The expert-based approach resulted in a response rate of 100% for provisioning ESSs. The literature-based approach revealed links for 99 matrix cells out of 136 (73%), indicating low uncertainty concerning MMs’ effects on provisioning ESSs. However, literature was only found for 35% of the links of ESSs relevant for water supply, of which ‘water for non-drinking purposes’ revealed literature for two links only. Following the expert-based results, ‘water for non-drinking purposes’ is not affected by the implementation of the majority of MMs (ten out of 17). For the assessment of the ESS ‘wild animals and fish’, the experts sometimes differentiated their evaluation between wild animals on land and fish. Generally, the literature review revealed mostly literature on provision of fish for consumption, as literature on game species diversity and abundance in the specific context of floodplains is scarce.

3.1.2. Regulating services

For regulating ESSs, the expert-based approach resulted in a response rate of 87%. The literature-based approach revealed links for 89 matrix cells out of 187 (48%). Considerable differences between the individual regulating ESSs were found. The most literature was found for ‘habitat maintenance’, and there was virtually no uncertainty among the experts. The expert response was low for the ‘retention of Corg’, ‘retention of N’ and ‘retention of P’ group (2.57 ± 1.47 SD, range 0–5); for the ‘retention of Corg’ ESS, 17 out of the 21 possible combinations of MMs and ESSs were only answered by a single expert (response rate 1.1 (±0.19 SD, range 0–2)). The literature-based approach revealed links for 27 matrix cells out of 51 (53%). In comparison, the experts assessed some links as negative, which could not be confirmed by the available literature. For the remaining ESSs related to the mitigation of flows, the expert-based approach resulted in a response rate of 100%. The literature-based approach revealed links for 44 matrix cells out of 119 (37%). For ‘WWTP construction’ (MM1) and ‘invasive species control’ (MM14), no literature at all was found for the ESSs related to the mitigation of flows, and the experts did not indicate a correlation either.

3.1.3. Cultural services

For cultural ESSs, the expert response rate was only 3.52 (±1.89 SD, range 1–6) with diverging expert opinions, indicating a high uncertainty. The response rates for the ESSs of ‘landscape aesthetics’ (4.24 ± 1.39 SD, range 2–6) and ‘natural and cultural heritage’ (4.05 ± 1.15 SD, range 2–6) were higher than for ‘unspecific interactions with the riverine ecosystem’ (2.86 ± 1.93 SD, range 1–5) and ‘water-related activities’ (2.95 ± 1.75 SD, range 1–5). The literature-based approach revealed links for 51 matrix cells out of 78 (17 MMs and four ESSs), which equals 65%. The available literature was often indirect, mentioning recreational possibilities in general. Therefore, a clear distinction between the four cultural ESSs was challenging. Nevertheless, for 69% of the links where the experts did not vote unanimously or chose an ambivalent evaluation, the link could be indicated as positive after consulting the literature.

3.1.4. The final matrix

The final matrix (Table 3), with 391 cells, was based on 214 cells for which more than three experts
answered and literature was found. For 143 cells, no literature was found, and here the final matrix relied on the opinion of a minimum of three experts. For 17 cells, fewer than three experts gave an opinion but literature was found, while for another 16 cells between one and three experts stated an opinion yet no literature was found. For one cell, no literature was found nor did any expert state an opinion. The cells with high uncertainty, meaning a low number of expert opinions and a low number/quality of studies found, are marked with an asterisk (32 cells), or could not be linked (2 cells).

3.2. Matrix of management measures and ecosystem services

The results show that the MMs affected the selected array of ESSs in various ways (Table 3). Overall, in 24% of the matrix cells, there was no effect of the respective MM on ESS provision, in 10% the links were negative, in 1% highly negative, in 34% positive, in 10% highly positive, and in 20% ambiguous.

For all MMs, except for ‘flood retention areas and dams’ (MM17), more positive than negative effects on ESSs were found (Figure 1). The multifunctionality spectra (Figure 2) illustrate more detailed effects on provisioning services (red), regulating services (green) and cultural services (blue). Here, the negative effects of MM17 are related to regulating ESSs, whereas most of the other ESSs are linked ambiguously. The most positive effects (Figure 1) were found for measures related to ‘habitat maintenance’ (MM10), ‘floodplain restoration’ (MM7) and ‘flood risk reduction on agricultural land’ (MM16), as these MMs all have either positive or highly positive effects on 16 ESSs, across all types (i.e. provisioning, regulating and cultural ESSs) (Figure 2). This is followed by ‘dyke relocation’ (MM8), which had positive effects on 15 ESSs. The lowest number of effects on ESSs was found for the MM of ‘WWTP construction’ (MM1) and for ‘stocking’ (MM12). However, for these two measures, no negative effects on ESSs were identified, which is similarly the case for ‘counteraction of acidification’ (MM4), ‘bedload budget’ (MM11), ‘invasive species control’ (MM14) and ‘recreation impact control’ (MM15) (Figures 1 and 2). Notably, ‘flow regime restoration’ (MM6) and ‘floodplain restoration’ (MM7) both exert highly positive links on a high number of regulating ESSs (Figure 2). Overall, 51% of the links for provisioning ESSs related to agricultural production were negative. The only three MMs that had positive effects on agriculture or forestry are ‘counteraction of acidification’ (MM4), ‘invasive species control’ (MM14) and ‘recreation impact control’ (MM15). The provision of the three ESSs relevant for water supply is influenced positively by many MMs. Despite the aforementioned uncertainties, the majority of MMs (37%, 25 matrix cells out of 68) were evaluated as positive for the ESS ‘retention of C_{org}’, ‘retention of N’ and ‘retention of P’, and no negative links emerged. The ESS of ‘habitat maintenance’ benefited from more MMs in a highly positive way (11 out of 17; 65%) than any other ESS. In contrast, ‘flood retention areas and dams’ (MM17) was shown to have a negative effect on four regulating services. Regulating services were otherwise rarely affected negatively by MMs; negative effects were only identified for the ESS ‘drainage capability’. Cultural ESSs were positively influenced by most MMs (69% of the links), with the remaining links being mainly ambiguous.

The MMs differed substantially in terms of the profile of their effects on the various ESSs. These specific multifunctionality spectra are discussed in detail.

Figure 1. Effects of management measures (MMs) on the studied set of ecosystem services (ESSs) (n = 23) according to the number of links (by colour, see legend) in the matrix.
3.2.1. MM1: construction or upgrades of wastewater treatment plants (WWTP)

‘WWTP construction’ (MM1) yielded solely positive results, and no uncertainties remained (no link was answered with ‘ambiguous’). This MM influenced the ESS ‘surface water for drinking’ and ‘habitat maintenance’ highly positively, but had little effect on regulating ESSs (Figure 2).

Cleaner river water may have an influence on ecological status, as reflected, e.g. by an increase in species diversity or the abundance of fish (UBA 2017), which in turn is positive for fishing (Harrison et al. 2014) and...
thus for the ESS of ‘wild animals and fish’. With WWTPs, pollutants in the water such as mercury can be reduced, and thus in the food chain as well (BMUB and UBA 2016), which is also positive for the ESS ‘habitat maintenance’. By reducing microbial contamination and other pollutants, MM1 leads to greater attractiveness as well as a higher recreational value for swimming, sunbathing, water sports and nature observation (European Rivers Network 2015; Jürging and Patt 2005; Meyerhoff et al. 2010; TEEB DE 2016). In general, it is necessary to consider that lay people perceive clear waters to have better quality and increased aesthetics, even if there is no correlation to better ecological status as such (Cottet et al. 2013).

### 3.2.2. MM2: the reduction of pollution from agriculture; MM3: the establishment of buffer zones; MM16: flood risk reduction on agricultural land

‘The reduction of pollution from agricultural’ (MM2), ‘the establishment of buffer zones’ (MM3) and ‘flood risk reduction on agricultural land’ (MM16) (see Figure 2) all have similar effects on ESSs. MM2 and MM3 are measures outlined in the WFD to reduce pollution from agriculture (MM3 can also be seen as a sub-measure of MM2, but was considered separately here, because of its high importance), and MM16 is from the FRD. MM16 includes similar measures (e.g. intercropping, conservation agriculture), but is more multifunctional and comprehensive than MM2, as it functions over a larger area. Farmers receive funding for establishing buffer zones in agricultural environments, implementing climate measures, and greening programmes laid out in the CAP (MULEWF 2015).

The reduction of surface water pollution from agriculture may be accomplished by changes in agricultural practices such as conservation tillage (Bender et al. 2008), refraining from ploughing (Hillebrand et al. 2006), changing to organic agriculture (including year-round vegetative land cover, intercropping, eliminating mineral N fertiliser and reducing livestock density) (Schäfer et al. 2007), changing fertilisation practices (Dullau et al. 2012) (all MM2), establishing buffer zones (MM3) (Semlitsch and Bodie 2003; Mayer et al. 2007; Henschel et al. 2014; MULEWF 2015) or permanent pasture (MM16) (Tussing et al. 2016), and constructing woodlands (MM16) (Nisbet et al. 2011). These all may have a positive effect on many ESSs, but a negative influence on provisioning services related to agriculture. MM16 revealed more positive links (for a total of 16 ESSs) than MM2 (11 ESSs). Lower pesticide use and conservation tillage increases the density of soil organisms (Dullau et al. 2012) leading to more macro pores (Bender et al. 2008), which consequently increases water storage capacity (Scheffer 2010) and thus flood protection (Baumgarten et al. 2012; BiN 2014; Deasy et al. 2014; Juniper 2014; EEA 2017). However, the effect of land use on flood mitigation is significantly under-researched (Deasy et al. 2014). Wide buffer zones that include well-developed riparian vegetation (Macfarlane et al. 2014; EEA 2017) or hedgerows and other small-scale structures (Schüler 2007; Archer et al. 2013) have the ability to slow down floods (Lovell and Johnston 2009). The experts decided on an ambiguous link between MM3 and the ESS ‘flood risk regulation’, but since no negative effect of buffer zones on floods could be found in the literature, the present study determined there to be a positive link. The EEA (2017) even reported a highly positive effect of buffer zones on flood risk reduction. Lower eutrophication of rivers leads to higher landscape attractiveness (Cottet et al. 2013). Insofar as agricultural measures increase biodiversity (Stinner and Blair 1990; Gibson et al. 2007), the aesthetics of the landscape are indirectly enhanced (TEEB 2012). Moreover, less intense farming preserves the countryside and thus cultural heritage (Bignal and McCracken 1996; McGurn and Moran 2010; Kowatsch and Schäfer 2015). Buffer zones support structural elements of the landscape (Henschel et al. 2014) and may serve as an attractive recreational area to observe plant communities and wildlife (Senatsverwaltung für Stadtentwicklung und Umweltschutz Berlin 2011; Clough 2013; Henschel et al. 2014; Macfarlane et al. 2014).

### 3.2.3. MM4: the counteraction of acidification

‘The counteraction of acidification’ (MM4) includes liming (Bolan and Hedley 2003) and (rarely) conversion to near-natural forests.

MM4 has no negative effects on ESS, and several positive links were found. Liming may increase the abundance and richness of acid-sensitive invertebrates (Sandey and Romundstad 1995; Mant et al. 2013), which in turn relates to an increase in some regulating ESSs. However, there is very little literature available. In general, the effects of MM4 are uncertain (Hindar et al. 2003; Lundström et al. 2003; Löfgren et al. 2009; Ouimet and Moore 2015).

### 3.2.4. MM5: the reduction of water abstractions

‘Water abstraction reduction’ (MM5) has a negative effect on the agriculture-based ESSs and positive or ambiguous or no effects on the remaining ESSs (see Figure 2). In Germany overall, less than 2% of the total agricultural area is artificially irrigated, with considerable differences between the federal states (UBA 2016). Without irrigation, cereal production on irrigated land would decrease in Western Europe by 1.2% (Siebert and Doll 2010). Moreover, reduced
water abstractions lead to higher water flows in rivers, with positive effects for recreational activities such as swimming, bathing, water sports and boating (LAWA 2007), as well as hyporheic flow and riparian soil humidity, which has benefits for species diversity as well as aquatic and terrestrial vegetation (REFORM 2015).

3.2.5. MM6: the restoration of the natural flow regime; MM7: floodplain restoration; MM8: dyke relocation, slotting or dismantling
Near-natural floodplains are important for retaining water during floods, purifying water, and serving as a habitat for a multitude of endangered animal and plant species (BMU, BfN 2009). However, the potentials of natural floodplains to retain and slow down flood peaks have been diminished because of dyke construction (EC 2007; Mehl et al. 2013), and therefore floodplain restoration is often combined with dyke relocations (Bender and Schäfer 2009; EEA 2017). The measures of ‘flow regime restoration’ (MM6), ‘floodplain restoration’ (MM7) and ‘dyke relocation’ (MM8) provided many positive links to regulating services, but negatively affected the provision of services ‘cultivated crops’ as well as ‘plant resources for agricultural use’ (Figure 2). MM6 and MM7 have the most positive links, while MM8 has fewer negative links. The ESSs related to retention are enhanced by enlarging floodplain areas and an increased flooding frequency (Natho and Venohr 2014) due to lower flow velocity in rivers (Schulz et al. 2003), higher hydrological connectivity and increased processing in the hyporheic zone (Rücker and Schrautzer 2010). Literature for the links of MM6, which included the re-establishment or securing of minimal flow in addition to hydroparking, mainly focused on the most evident ecological effects on biological communities – thus the ESSs of ‘habitat maintenance’, ‘wild animals and fish for consumption’ and ‘surface water for drinking’, but indirect impacts are under-researched (Bejarno and Nilsson; Bejarno et al. 2017; Hauer et al. 2017).

3.2.6. MM9: the restoration of longitudinal connectivity; MM10: habitat improvement
‘The restoration of longitudinal connectivity’ (MM9) and ‘habitat improvement’ (MM10) revealed similar links for thirteen of the ESSs. Of these, MM10 had a higher number of positive links and was more multifunctional than MM9, particularly with regard to the ESSs ‘metabolism of matter’, ‘habitat maintenance’ and ‘mitigation of flows’ (see Figure 2). ‘The restoration of longitudinal connectivity’ (MM9) is designed to enhance seasonal migration, and the spawning and spreading possibilities of fish and invertebrates; this in turn improves habitat quality by restoring the ecological connectivity of rivers (BMUB and UBA 2016, 2017).

3.2.7. MM11: the improvement of bedload budget and sediment management
A natural river transports significant amounts of sediment downstream, which is interrupted by dams; this results in the incision of the channel bed (Kondolf 1997), with negative effects on spawning habitats for fish (Kondolf 1997; Bunte 2004; Barlaup et al. 2008; Kondolf et al. 2014). Pressures related to the removal of sediments are often reported by the HD, but not by the WFD (ETC/ICM 2015). Hence, it seems that the significant and multifunctional benefits of ‘bedload budget improvement’ (MM11) (eleven ESSs are improved, with at least one from each ESS group) have so far not been fully recognised in restoration strategies.

3.2.8. MM12: stocking
‘Stocking’ (MM12) is the attempt to raise the number of juvenile fish that will grow to recruits, or to increase the number of mature fish that can then be caught (Arlinghaus et al. 2017). It is a very popular practice among angling associations, but it bears ecological risks if it is not performed in a sustainable way (Arlinghaus et al. 2015). Stocking yields the lowest increase in ESSs compared to all other MMGs, and neither positive nor negative side effects on other ESSs could be identified (see Figure 2). Hence, the establishment of regulations for sustainable fishing and habitat improvements may represent more efficient MMGs than stocking would do (Arlinghaus et al. 2017).

3.2.9. MM13: the prevention of adverse impacts of drainage
The purpose of land drains is to reduce the waterlogging of agricultural areas and increase possible agricultural productivity (Chapman et al. 2005; Posthumus et al. 2010) by improving soil aeration conditions (Tiemeyer et al. 2006, 2016). Problems arising from agricultural drainage relate to nutrient and sediment emissions to surface waters (Backhaus et al. 2005; Bockholt et al. 2006; Coelho et al. 2010; Henschel et al. 2014) and to changes in runoff behaviour (Fohrer et al. 2007). For MM13 as well as the ESS “drainage capability”, the cited literature fails to directly evaluate any MM’s effects on the ESSs, and so far, studies on the potential positive ecological effects of dismantling drainage systems are almost completely missing.

3.2.10. MM14: the prevention or control of the adverse impacts of invasive species; MM15: the prevention or control of the adverse impacts of recreation
‘Invasive species control’ (MM14) and ‘recreation impact control’ (MM15) were found to be promising MMGs, with only positive effects on ESSs. Invasive species represent a major threat to aquatic ecosystems, as they cause a severe decline in biodiversity
(Tockner and Stanford 2002; Hussner et al. 2017). However, few studies on management methods for invasive aquatic species are available (Schindler et al. 2016; Hussner et al. 2017); the LAWA-BLANO catalogue also fails to specify MM14. MM14 can reduce the impact of invasive species on the water flow and water availability in irrigation and drainage systems (Hussner et al. 2017) or their direct impact on agricultural yields (e.g. nutria feeding on crops) (Carter and Leonard 2002). Moreover, there is a risk of biofuel crops and tree species becoming invasive themselves (McCormick and Howard 2013; Hohensinner et al. 2015).

The prevention or control of the adverse impacts of recreation (MM15) is important, as tourists affect aquatic ecology through the addition of nutrients and other chemicals into the water column as well as by direct physical disturbance to sediment and vegetation (Mosisch and Arthington 1998; Marion and Farrell 2002; Hadwen et al. 2003; Reid and Marion 2005; Törn et al. 2009; Pickering et al. 2010) and disturbances or damage to vegetation (Fenn et al. 1976; Marion and Farrell 2002; Cole 2004). Some recreation activities (e.g. campfires, forest trails) compact soil, which reduces water infiltration rates; this in turn leads to increased runoff and erosion potential (Fenn et al. 1976; Marion and Farrell 2002; Cole 2004; Schüler 2007), indicating a positive link between MM15 and the ESSs of ‘flood and drought risk regulation’ and ‘soil formation in floodplains’, which the experts did not address.

3.2.11. MM17: flood retention areas and dams

Overall, MM17 had more negative than positive effects on ESS provision. Retention areas and polders represent so-called green infrastructure, which includes natural and semi-natural areas, while longitudinal barriers include so-called grey infrastructure solutions and usually are made of concrete (EEA 2016, 2017). MM17 was the only MM to yield negative effects for the ESSs of ‘mass flow/sediment regulation’, ‘soil formation in floodplains’, ‘local temperature regulation/cooling’, and ‘habitat maintenance’. The effects of MM17 on ESSs are generally the mirror image of those of MM9.

4. Discussion

4.1. Combining expert-based and literature-based approaches

The matrix between MMs and ESSs was established by combining expert evaluations with a literature review in a three-step approach. For the first step of the expert-based approach, 4.8 (±1.8 SD, range 0–6) experts on average stated an answer, which was comparable to the response rate of 4.1 (±1.1 SD, range 3–6) reported by Schindler et al. (2014). Overall, the response rate was highest for provisioning ESSs, whereas the lowest response rates related to cultural services and nutrient retention. Campagne et al. (2017) have recommended a minimum expert panel size of 15 for expert-based matrix approaches that link land cover types to ESSs. To maintain a reasonable timeframe, the first step of our expert-based approach included five to six experts, followed by a second step where all 17 experts could express their potential disagreement on the matrix links established by the smaller expert groups as well as through the literature-based approach. This approach is in line with the proposed ‘partial individual fill in’ and ‘adjustment in consensus’ as described in Campagne and Roche (2018) and added the component of asking the experts to reflect the results of the literature.

The literature review identified usable literature sources for 60% of matrix cells, most of them for provisioning ESSs, with the fewest for regulating ESSs. To establish a measure of certainty for the literature-based approach, we initially considered counting the number of studies found for the individual links between a given MM and ESS. However, it turned out that for some ESSs, there is only a small number of precise studies available that directly investigated the link between MM and ESS, whereas for other links a large amount of literature existed. However, those studies sometimes only vaguely assessed the respective ESSs. Due to this situation, we concluded that the number of studies alone failed to provide an appropriate measure of certainty for the literature-based approach. With the consulted literature and the second step of the expert-based approach, it was possible to establish consistent links for 357 of the 391 cells. The 32 remaining cells had a low level of scientific certainty (asterisk in Table 3) and two cells could not be linked. Ambiguity and uncertainty are widespread in ESS assessments (Hou et al. 2013; Jacobs et al. 2014), but are rarely reported in a transparent way.

The matrix approach combining expert evaluations, an expert panel discussion and published scientific and grey literature enabled us to transparently report the data basis for the links and to uncover and reduce some uncertainties. On the one hand, the scope of both types of information source differs. More specifically, it is difficult to assess issues of scale from the literature as case studies are very context-specific, whereas it was possible to use expert knowledge to evaluate the strength of a link. The literature-based approach in turn enabled the study to reveal a comprehensive picture about the possible side effects of a given MM, which might otherwise be overlooked by expert opinion alone. Moreover, the approaches complemented each other, meaning that, for some cells, literature-based knowledge provided
information to be entered where the experts were not able to evaluate, and vice versa.

This enabled the study to identify and differentiate between knowledge gaps as well as links with no causal relationship. First, the ESSs that are directly supported by the MMs are well described in the literature. Here, the MMs causing the greatest improvement of ESSs correspond to the results of Schindler et al. (2014). However, the majority of studies focus on pressures, and thus not directly on MM. In particular, the effects of MMs on the regulating ESSs of ‘retention of N’, retention of P’ and ‘retention of C_{org}’, as well as on cultural services, revealed considerable research gaps (see Section 3.1), as here both approaches failed to reveal clear results. Second, the small number of studies found for some ESSs could be related to the different use of terms within specific science disciplines, among different stakeholders, and as a result of inconsistent translations. The differing use of scientific terms between disciplines is a known problem and can be a significant hurdle (Donovan et al. 2015). Third, unfortunately there are very few literature sources that prove that a measure really has no effect on an ESS. Here, the combined approach enabled us to differentiate between knowledge gaps and links that had no causal relationship. Our resulting matrix with 24% ‘no correlation’ cells is comparable to the findings of Schindler et al. (2014), who found 29.3% of the links to have ‘no effect’; overall, they took a more general approach regarding the MMs they evaluated. Due to our focus on MMs that were relevant for Germany and were restoration-targeted, the final matrix could assist conservation and water planners in Central Europe.

4.2. Linking management measures and ecosystem services

The inclusion of all main groups of ESS represents a useful supplement to determining the ecological status of rivers, as it enables to select effective management measures with the highest benefits for ESSs, and thus contribute to human well-being. The most positive effects were found for MMs related to ‘habitat maintenance’, ‘floodplain restoration’ and ‘flood risk reduction on agricultural land’ including provisioning, regulating and cultural ESSs. MMs without trade-offs included ‘WWTP construction’, ‘acidification counteraction’, ‘bedload budget’, ‘stocking’, ‘invasive species control’ and ‘recreation impact control’. However, there are also only two positive links for ‘stocking’, and its multifunctionality therefore is low.

The experts involved often saw no effect of ‘recreation impact control’ on ESSs. Measures designed to reduce recreational impacts were not assessed by Schindler et al. (2014), but they found no effects of recreational use on ESSs as such. However, literature has indicated various effects of recreation on the ecosystem. In contrast to the expert evaluations, six matrix cells showed a positive link between ‘recreation impact control’ (MM15) and the ESS provision in the final matrix. Unfortunately, for the most part the literature has not yet directly investigated the link between pressures or a specific measure and the respective ESS. Hence, further research is needed to identify effective measures to reduce the impact of recreation. A negative correlation between conservation and recreation has been reported (Eastwood et al. 2016), but in a choice experiment, people valued ecological integrity higher than their own recreational benefits (Frör et al. 2016). This allows for the assumption that people might be willing to accept constraints on recreation if it serves the purpose of conservation.

Links between MMs and ESSs from the cultural services group other than landscape aesthetics and ecosystem-based recreation – in the case of our work, these were called ‘water-related activities’ and ‘unspecific interactions with riverine ecosystem’ – are in general rarely studied (Chan et al. 2012; Hauck et al. 2014). In our work, expert knowledge as well as literature were sparse for the cultural ESSs. Schindler et al. (2014) defined the two ESSs of ‘landscape aesthetics’ and ‘natural and cultural heritage’ jointly as one single ESS: ‘aesthetic, heritage’. Our results revealed the same links in 13 out of 17 MMs. It is known that cultural services are the most difficult ESSs to quantify, and thus there is a lack of their integration into management, planning and policies (Chan et al. 2012; Eastwood et al. 2016; Holleland et al. 2017). Nevertheless, ‘drainage impact prevention’ was the only measure where no literature for any link of cultural services could be found; for all other measures, literature is available at least for the ESS ‘water-related activities’. In general, ‘drainage impact prevention’ as well as ‘stocking’ were the MMs with the lowest amount of literature found (four references across all ESSs for MM12 and six references for MM13 respectively; see the literature matrix in the Online Appendix). Also, the ESS of ‘drainage capability’ is not assessed in other ESS classifications (e.g. Schindler et al. 2014).

Besides cultural services, the experts’ response rate was also low for the ESSs dealing with the retention of nutrients. This was particularly the case for the ESS ‘retention of C_{org}’. At the same time, the literature review did not reveal a single study that directly investigated MM impacts on this ESS. The scientific certainty for the links drawn for these ESSs is low. The research gaps can be explained by the high level of complexity as well as still remaining uncertainties of the carbon cycle (Heimann 2010; Li et al. 2017; Nakayama 2017). Moreover, only a few studies deal with organic carbon stocks present in floodplains (Scholz et al. 2012), and Schindler et al. (2014) did not examine nutrient retention at all.
4.3. Towards integrated management approaches

The matrix approach allowed us to transparently show possible side effects of MMs taken from the WFD and the FRD on ESS for the first time. Schindler et al. (2014) found a higher negative and a lower positive share of links, which is due to their inclusion of technical measures. The restriction to restoration-targeting measures increased the share of positive links in our work. ‘Flood retention areas and dams’ (MM17), a measure from the FRD, was the exception in our work. For this MM, the results showed a higher share of negative links, comparable to the results of Schindler et al. (2014). Moreover, significant knowledge gaps were identified for cultural and retention ESS. The implementation of MMs obviously generally increases the provision of most ESS. In other words, most MMs are multifunctional, which is one favourable aspect for developing integrative management practices supporting multiple sectoral policies.

The results of our study may be applied in any problems of river or floodplain management where several management options are available. For instance, in Germany, there are national programmes to improve flood regulation (in response to higher floods due to climate change) and at the same time to restore natural floodplains, including their biodiversity. These programmes often cause conflicts at the local scale, because they aim to make use of the same floodplain areas. This means that flood retention may be either carried out by applying MM8 ‘Dyke relocation, slotting or dismantling’ or by applying MM17 ‘Flood retention areas and dams (including polders)’. In a case study on an 80 km section of the Danube in Bavaria (Pusch et al. 2018), two management scenarios were under investigation, including different combinations of both MMs. In such situations, the matrix developed in this paper could serve as a tool for practitioners to get an initial impression of potential effects. As Figure 2 clearly shows, MM8 has positive effects on 15 ESSs, in contrast to only two positively influenced ESSs in the case of MM17. Podschun et al. (2018b) assessed 13 ESSs regarding the status quo and respective changes in the scenarios, which corresponded to the estimations made from our matrix. In conclusion, the matrix presented here summarises scientific evidence that has not previously been available with such clarity. This evidence can now be used to support decision-making processes in early stages, by stimulating discussions about unintended negative consequences of an MM, or any underestimated added value regarding the increased provision of multiple ESSs. As such, the ESS approach enables decision-makers to balance various aspects of human activities and interventions, thus supporting efforts to improve current management practices and make them more sustainable (Kistenkas and Bouwma 2018). Such integration of ESS concepts into EU policies confers various advantages, such as the exploitation of cross-sectoral synergies and the management of trade-offs between ESSs (Bouwma et al. 2018). Many EU policies aim to tackle similar pressures to that of the WFD, and therefore contain similar MMs. For example, buffer zones are also listed as an MM in the Common Agricultural Policy (Hauck et al. 2014). Scenic beauty, for example, is also relevant in the European Landscape Convention, and therefore synergies with this policy can also be exploited if cultural ESS are detected (Seardo 2015). Overall, additional, more detailed research on different WFD MMs and their synergies and trade-offs, as well as on synergies across different directives (CAP, Landscape Convention etc.) is needed to foster integrated management approaches. A matrix approach linking ESSs and MMs that combine expert-based and literature-based approaches, such as the one presented here, can provide a valuable basis for cross-sectoral dialogues among stakeholders.

5. Conclusion

The matrix described here provides a sound approach for assessing the effects of MM in rivers and floodplains on the provision of ESS. The combination of a literature review with an expert-based assessment proved to be a valuable approach to get a comprehensive impression of the scientific evidence, and the uncertainties and gaps in current research. The findings indicate that the ESSs provided by rivers and floodplains interact very closely, and trade-offs arise with the implementation of MMs. Overall, restoration-targeted management measures consistently increased the multifunctionality of a floodplain landscape by enhancing the provision of various ESSs. However, some ESSs may be negatively influenced. The results of this work suggest that provisioning services – especially agriculture-based ESSs – are expected to decrease, while regulating as well as cultural services increase.

In conclusion, the matrix presented here summarises scientific evidence in a transparent way and thus can support decision-making processes when 1) selecting MMs with the highest number of positive effects for ESS provision and/or the lowest number of negative effects, 2) uncovering added value of MMs, potentially increasing their acceptance for implementation, and 3) stimulating cross-sectoral discussions in situations with conflicting legal management objectives.
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