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Soil security in floodplain and river restoration projects

Mariam El Hourani *, Gabriele Broll

University of Osnabrueck, Institute of Geography, Seminarstr. 19a/b, 49074 Osnabrück, Germany

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A B S T R A C T

Floodplains and their soils provide a vast range of ecosystem services for nature and humans. At the same time, however, these ecosystems are among the most degraded in the world. During the past decades an increased effort has been made towards the restoration of floodplains and rivers; however, in such projects, soil is often overlooked. To assess the actual status in Germany an online survey has been conducted to investigate the obstacles to soil protection from the restorer's view, and to find ways to better integrate soil protection in such projects. The results show that soil is already present in project planning and implementation, but a special focus is set on pollution. Not all aspects of the soil are equally considered, usually because of financial constraints. Besides the financial aspect, other obstacles include complicated regulations on soil protection in Germany and a lack of soil awareness. There are efficient tools to avoid harmful soil changes on construction sites like the Pedological Construction Supervision (PCS), however, this is often seen as an additional financial and organizational burden. To better integrate soil in restoration projects, a special interest lies on the connectivity component of the Soil Security concept that aims to increase soil awareness of all stakeholders. This is accompanied by planned new soil legislation on soil protection in Germany.

Introduction

Floodplains and their soils are important parts of the river ecosystems and provide crucial functions and services like the buffering of nutrients and pollutants (Malmqvist and Rundle, 2002; Adhikari and Hartemink, 2016; Christiansen et al., 2020; Nolan et al., 2021). Today, floodplains are among the most threatened ecosystems in the world (Malmqvist and Rundle, 2002; Tockner and Stanford, 2002; Arsénio et al., 2020). Many floodplains worldwide are degraded due to anthropogenic reasons like dam building, and most floodplains cannot deliver the ecosystem services to the same extent as natural floodplains anymore (Vanneuville et al., 2016; Best, 2019; Palmer and Ruhi, 2019; Christiansen et al., 2020; Mohan et al., 2022). Approximately 70–90% of Europe's floodplains are degraded (Vanneuville et al., 2016); in Germany, only 9% of the floodplains are not modified or are very slightly modified and still fulfilling their functions and services. About 33% of the German floodplains are significantly modified due to hydraulic engineering measures but can still contribute to the floodplain services in a limited way. The remaining 58% are heavily modified and reflect the continuing high pressure on rivers and floodplains (Koenzen and Kurth, 2021).

Since the Water Framework Directive (WFD; Directive 2000/60/EC) came into force in 2000 in the European Union, this has led to many restoration projects of rivers and floodplains throughout European countries (Morandi et al., 2014; Albert et al., 2021; El Hourani et al. 2022). But as the state of the German floodplains shows, there is still a great need for further restoration initiatives (Koenzen and Kurth, 2021). Restoration measures aim at the improvement of the natural state of rivers and floodplains to fulfill their natural functions and services like the filtering and storing of water, sustaining high biological diversity, providing habitat for plants and animals, natural flood protection and biogeochemical processes (Christiansen et al., 2020; ECRR, 2019; Palmer et al., 2005). In many cases the structure of rivers is degraded due to anthropogenic activities (dams, straightening of rivers, other structures in or along the river) (Christiansen et al., 2020; Palmer and Ruhi, 2019; Vanneuville et al., 2016). To improve the hydromorphological structure of the river, major soil-moving activities are necessary (Palmer et al., 2014), which often result in the use of heavy machinery for the reconstruction of the channel or the removal of dams (Feldwisch, 2012). This means that in these cases the soil is almost always affected by soil removals, allocations, or applications (Feldwisch, 2012; Laub et al., 2013; Palmer et al., 2014). These construction activities can have a negative impact on the soils; meaning that the soils cannot fulfill their functions and ecosystem services to their full extent.

* Corresponding author.
E-mail address: mariam.elhourani@uni-osnabrueck.de (M. El Hourani).

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Soil impacts can for example lead to soil compaction, resulting in reduced water infiltration rates and reduced plant growth (Feldwisch, 2012). This restoration trend in general has been observed in many other parts of the world, as floodplains and rivers are crucial for ecosystem functioning and the provision of ecosystem services (Palmer et al., 2014). This global trend of restoration efforts, not only in floodplains and rivers, but also in many other ecosystems, has culminated in the declaration of the UN Decade on Ecosystem Restoration (UN-DER) running from 2021 through 2030 and fostering the revival and protection of ecosystems (Aronson et al., 2020; Abhilash, 2021; n.A., 2022). For riparian ecosystems there is still a great need for restoration, as people are highly dependent on riverine ecosystems, as reflected by the many UN Sustainable Development Goals (SDGs) these ecosystems contribute to (Palmer et al., 2014; Basak et al., 2021; Mohan et al., 2022). Many of the SDGs are also connected to soil (Bouma, 2014; Abhilash, 2021; Nolan et al., 2021). The UN Decade on Ecosystem Restoration now offers the possibility to finally focus on these soil related goals, too (Nolan et al., 2021; Smith et al., 2021). Soil is key to many challenges humankind is already facing, or will face in the future, like Food Security, Water Security, Energy Security, Biodiversity Protection, Climate Change Abatement or Ecosystem Service Delivery (Bouma and McBratney, 2013). They are all connected with each other, and soil is important in all of these challenges (Herrick, 2000). This leads to the new concept of Soil Security introduced by McBratney et al. (2014), comprising many more dimensions than other concepts. Today, soil is often overlooked in restoration projects due to a lack of soil awareness and the importance of soil, its complexity and resource constraints (Nolan et al., 2021). The development of floodplain soils is highly dependent on the adjacent river and the flow regime. Their physical, chemical, morphological, and mineralogical characteristics are also influenced by the alluvial parent material, which can vary from fine material to coarser materials like sand or gravel (Boettinger, 2005). The deposition and transport of material, for example organic matter, are also characteristic processes in the formation of alluvial soils (Gerrard, 1987). In the World Reference Base for Soil Resources (WRB) recent floodplain soils can be classified as Fluvisols. Over time, these initial soils can develop into different soil types with varying properties, for example, Fluvic Histosols or Histic Gleysols (IUSS Working Group WRB 2022). Floodplain soils play a crucial role in the riverine ecosystem; therefore, they also need special attention in restoration projects (Zausig et al., 2020).

An effective tool to avoid harmful soil changes in any kind of construction measure is the Pedological Construction Supervision (PCS). The PCS is a precautionary soil protection concept for construction projects, originally developed in Switzerland and now used in the whole German-speaking region. The goal of the PCS is to preserve the soil and its natural functions, or to restore them after a construction measure. It protects the soil against physical and material impairments during a construction project, such as compaction, erosion, or contamination. To be able to do this, the PCS should be involved in the project as early as possible, preferably at the beginning of planning. The PCS should be part of a restoration project during the entire implementation phase and is responsible, for example, for the setup of the construction site or for the appropriate use of different construction machines at different soil moisture levels to avoid compaction. Finally, monitoring is always one of the core tasks of a PCS (BVB, 2013; Bosold et al., 2022).

In the context of restoration, it might now be interesting to bring all these points together and have a closer look at the status of the protection of the soil in floodplain and river restoration projects. The perception of the soil from the restorer's point of view might give interesting insights and incentives for the future better integration of soil protection measures in floodplain and river restoration projects.

The objectives of this study therefore are:

1. To assess the obstacles to soil protection in floodplain and river restoration projects;
2. To review the status quo of soil protection in floodplain and river restoration projects;
3. To make recommendations on how soils can be better protected in floodplain and river restoration projects; and
4. To discuss the results in the context of Soil Security.

Theory

The Soil Security concept

Soil Security is a holistic and multi-dimensional concept considering the soil's contribution in meeting contemporary challenges, namely Food Security, Water Security, Energy Security, Climate Change Abatement, Biodiversity Protection and Ecosystem Service Delivery (Bouma and McBratney, 2013; Koch et al., 2013; Bouma, 2014; McBratney et al., 2014; Bennett et al., 2019). All these challenges are complex and inter-related (Bouma and McBratney, 2013), and soil is important in each of them (Herrick, 2000). But until recently, the soil's contribution has not been sufficiently considered in this context (Bouma and McBratney, 2013). Therefore, McBratney et al. (2014) introduced the new concept of Soil Security in which "security is used in the same sense as for food, water and energy" (McBratney and Field, 2015). It is important to note that earlier concepts have been developed, like soil health or soil quality (Karlen et al., 1997; Doran and Zeiss, 2000; McBratney et al., 2014); however, looking more closely at the concept of Soil Security it becomes clear, that this encompasses more dimensions than soil health and soil quality and that both concepts are an integral part of Soil Security. Soil Security covers aspects like the economic and natural value of the soils, education, and societal connection as well as policy, legislation, or requirements for conservation (McBratney et al., 2014; Bennett et al., 2019). All these aspects are summed up in five dimensions known as the five "Cs", namely capability, condition, capital, codification, and connectivity (McBratney et al., 2014). Capability covers biophysical aspects of the soil and deals with the question of "what can this soil be used for?" (McBratney et al., 2014; Bennett et al., 2019).

For alluvial soils the capability is strongly influenced by the parent material and the flow regime of the adjacent river. Alluvial soils can differ variably between soil subtypes; hence, different land use is possible, for example, alluvial forest, grassland, or other agricultural land. Capability "recognizes the intrinsic differences between different kinds of soil" (McBratney et al., 2014). Condition considers the deviation of key soil attributes under different land-use management, meaning a shift in capability (McBratney et al., 2014; Bennett et al., 2019). It asks if the soil is being improved, maintained, or degraded under a particular land use. In this context a restoration could improve the capability of alluvial soils, for example through the reconnection of river and floodplain. Regular flooding and closer natural conditions foster the development of alluvial soils; thus, capability and condition are interrelated (Bennett et al., 2019). The capital of the soil is the economic or ecosystem value that soil provides, like functions and services. These values can be of different forms like economic, social, or natural, and sometimes be difficult to quantify (McBratney et al., 2014; Bennett et al., 2019). There is so far no specific method to assess the capital of alluvial soils. Connectivity focuses on the question of "how much is known about the soil and its appropriate use?" and brings in a social component. Connectivity is important for all stakeholders, being land managers or the society that wish to use the soil's products and services (McBratney et al., 2014; Bennett et al., 2019). Connectivity considers whether the person who is responsible for the management of the soil has enough knowledge to sustainably manage the soil. Finally, connectivity also deals with soil education and appropriate tools for land managers like soil mapping or training (McBratney et al., 2014; Bennett et al., 2019). Soil users should be aware, for example, of soil water regimes (wetness of the soils) before using them, to prevent damage. Codification means the governance of the soil, comprising public policy, guidelines, legislation, and regulation leading to appropriate soil use (McBratney et al., 2014; Bennett et al., 2019). There is no legislation that applies specifically to alluvial soils in Germany or Europe (see Section 2.2). Soil security is a framework “designed to empower and reward good soil stewardship through a variety of approaches” (Bennett et al., 2019).

State of soil legislation in Germany and Europe

Soil protection in Germany is essentially determined by the Federal Soil Protection Act (BBodSchG), the Federal Soil Protection Ordinance (BBodSchV) and the respective federal state regulations (BVB, 2013). For historical reasons, the Federal Soil Protection Act is one of the more recent laws in German environmental protection, coming into force in 1998. Therefore, numerous other laws have priority over the soil protection law, insofar as impacts on the soil are regulated therein (BVB, 2013).

In the coalition agreement of the current Federal Government of Germany, a revision of the Federal Soil Protection Act was agreed. The Federal Soil Protection Act currently has a strong focus on the remediation of contaminated soils and has proven to be insufficient in the area of precautionary measures – especially with regard to climate protection, climate adaptation and the preservation of biodiversity. The complex relationship between soil protection law and other areas of law has also revealed enforcement deficits since the law came into force 24 years ago. For example, the current Soil Protection Act does not have its own approval procedure and the possibility to make soil protection regulations according to other laws is often not used. As a result, precautionary aspects of soil protection are often overlooked. In March 2022 a key points paper on the amendment (Novelle) of the German soil protection law was published. It is expected to come into force in 2023 (BMUV, 2022a).

Another difficulty exists in the case of projects that do not require a planning permit. In these projects, there is to date no possibility of obtaining knowledge about impacts on the soil. This bears a particular risk that precautionary soil protection will be overlooked (BMUV 2022b).

Another important law that applies to many larger floodplain and river restoration projects is the Environmental Impact Assessment Act (UVPG in Germany). This law identifies, describes, and evaluates impacts on the different protected natural compartments of ecosystems like soil, water, or landscape. The Environmental Impact Assessment (EIA) also contains measures for the prevention, reduction, and compensation of negative impacts on these compartments (Feldwisch, 2012).

At the European level, there is currently no soil legislation that applies to the whole European Union, like the Water Framework Directive. Current EU legislation addresses only some soil aspects, but soil legislation remains fragmented (Glæsner et al., 2014; Heuser, 2022). Some soil threats, mainly physical threats, like compaction, salinization and soil sealing are not covered at all (Glæsner et al., 2014). The current EU legislation mainly focuses on contaminants, for example with the Sewage Sludge Directive (Directive 86/278/EEC) or the chemical “REACH” system (Heuser, 2022). Finally, soil protection is achieved merely as a side effect of other laws (Heuser, 2022), but European soils are still degrading in the European Union as stated by the latest EU report on the environment (EEA 2019).

Since the proposal of a Soil Framework Directive in 2006 and its final withdrawal in 2014, there have been no further efforts for a European soil law until recently (Glæsner et al., 2014; Heuser, 2022). In 2019, the European Commission presented the European Green Deal, a strategy aiming at the European Union undergoing a sustainable transition and becoming the first climate neutral continent by 2050 (European Commission, 2019). The European Green Deal contains various sub-strategies, one of them, the EU Soil Strategy for 2030, is dedicated explicitly to the soil (European Commission 2021). By 2023, legal instruments for specific areas of action and a legislative proposal on soil health have been announced (Heuser, 2022).

Material and methods

Project selection

For this study, an online survey of 50 floodplain and river restoration projects as well as dike relocation projects in Germany, was carried out between summer and fall 2020. Due to non-uniform soil legislation among the EU member states and a lack of soil framework legislation, the focus of the case studies was set on Germany. Projects were chosen from a list and a map, both published in 2017 by the Federal Agency of Nature Conservation (BfN, 2022), where 175 projects in Germany were collected. The list is structured according to the river basin districts Danube, Elbe (including Eider), Ems, Meuse, Oder, Rhine, Weser, and Baltic Sea tributaries (including Schlei_Trave and Warnow_Peene). Within the river basin districts, individual rivers are then listed (e.g., in the river basin district Rhine amongst others the rivers Lahn, Lippe or Main etc.). The individual projects are then listed under each named river (e.g., renaturation Lahn Cappel). In the list, project names were recorded in a standardized way (composition of the river and the place name). Hence, the name of the project on the list could differ from the actual project names. This restoration project collection comprises restoration projects and dike relocations on medium and large rivers. Projects on small rivers and streams were not included on this list. This study is also limited to projects on medium to large rivers, as in these cases it can be assumed that the typical floodplain soils have developed in the adjacent floodplain. As the collection of projects on this list stopped in 2017, newer projects were not considered for this study.

Nevertheless, projects from the list were chosen as follows:

1. The German stream typology – ecoregion.

   The most important ecoregions in Germany “stream types from the highlands” and “stream types from the lowlands” were considered for this study. These two ecoregions include almost 72% of the watercourse length in Germany. The ecoregions “stream types of the Alps and the Alpine Foreland”, “ecoregion independent stream types” and “others” (e.g., artificial water bodies) were excluded, as they comprise only smaller parts of the watercourse length, or contain few large or medium rivers and mostly smaller streams and creeks. Within the ecoregion of “stream types from the lowlands”, marshland type (LAWA type 22) was excluded, as marshes are very special ecosystems with special soil types which do not belong to the characteristic floodplain soils. As a result, 23 projects have already been excluded from the list in the beginning.

2. River basin districts.

   There are ten river basin districts in Germany: Danube, Eider, Elbe, Ems, Meuse, Oder, Rhine, Schlei_Trave, Warnow_Peene and Weser (UBA, 2016). Not all river basin districts could be included equally. Especially in the coastal river basins Eider and Schlei_Trave, there are often already excluded river types (e.g., Marshes) or only very few projects in these areas have been recorded. Other river basin districts are located only partially in Germany (e.g., Meuse and Oder), which is why only a few projects were listed here. Most of the projects considered are therefore located in the large river basin districts in Germany: Danube, Elbe, Ems, Rhine, and Weser.

3. Data availability, contact person, project date and soil data.

   The next step was to use the project map and project list (BfN, 2022) to find information about the projects via extensive internet research. As in the project list project names were included in a standardized way (composition of the river and the place name). The project name in the list could therefore differ from the actual project names. In some cases, no connection could be made to real projects because of the name. This may be because some projects were implemented so long ago that no project pages have been created for them on the internet, or they were not (or no longer) to be found on the homepages of the responsible agencies. Those projects without available information, and other projects completed before the year

2000 (before the implementation of the Water Framework Directive), were excluded. In other cases, individual sections of the same project were listed as independent projects. However, related projects were again combined into one project for the purposes of this study. The search for information and contact persons was also complicated by the many different bodies carrying out the projects: municipalities, cities, districts, nature conservation associations or other organizations. Due to the federalism in Germany, authorities with similar topics usually have different names and different structures depending on the federal state, which made the search for responsible departments or persons even more difficult. Since the survey was specifically related to soil protection in floodplain restoration projects, there had to be a reference to soil in the projects. Thus, projects were excluded in which, for example, the seeding of floodplain-typical vegetation was carried out, without clear intervention in the soil, as well as other similar projects.

Finally, 50 suitable projects for the study were identified, of which 31 were located in the ecoregion “stream types from the highlands” and 19 in the ecoregion "stream types from the lowlands”. The projects were distributed more or less evenly across the federal territory of Germany.

Online survey

Since soil protection is not easy to quantify or to measure, and on-site examination of soil impact is very time-consuming and complex, a different methodological approach was necessary. Hence, data collection for this study was done indirectly through an expert survey. Another reason for the survey of experts was to ensure a certain practical relevance. The aim of the study was to examine concrete facts from soil protection practice, and to specifically address what the implementers identified as problems in practice. Experts, in this case, are representatives of the authorities who approved and managed the projects. Experts can also be the responsible persons in the nature conservation associations or other organizations respectively. Experts in general should be those who are best informed about the planning and implementation of the projects.

The survey was developed using the objectives from Section 1 and was reviewed by an expert before publication. The survey includes a quantitative and qualitative part. The quantitative section is divided into three subsections: first, the experts were asked for general project information, then the data on the status quo of soil protection in the projects was collected. The third part is about identifying problematic issues of soil protection in floodplain restoration projects. In the fourth, qualitative part, open questions were formulated in which the experts could specifically comment on suggestions for improvement of soil protection from their point of view.

All experts were contacted in advance by phone between June and August 2020 and were invited to take part in the online survey via email in September 2020. Five declined the request to take part in the online survey; thus, the link to the online survey was sent to 45 experts. The survey was open until the end of October 2020, and was hosted on “limesurvey,” provided by University of Osnabrueck. The survey was anonymous and did not allow any conclusions to be drawn about the participants. The quantitative part of the survey was later analyzed graphically, while the qualitative part was evaluated in a content analysis according to Mayring (Hug and Poschenik, 2010).

Results

General information about the projects

Of the 45 experts, 17 submitted the survey. One survey did not contain any answers and was therefore not considered for the evaluation, thus 16 questionnaires were completed in full. This corresponds to a response rate of 35.5%. Most experts were from the authorities who approved and managed the restoration projects. One was from a nature conservation association who managed the project. Two were project planners and site managers, and one expert was an ecological construction supervisor. The average planning for the projects was 5.2 years, while the average actual duration of implementation is slightly higher at six years, but the project implementation ranged between one and 17 years. Nine projects were part of larger cooperative projects. Three experts mentioned the EU-LIFE program in this context. Ten projects considered in this article belong to water management measures subject to EIA with a planning approval procedure. Six projects contained extensive measures without EIA obligation.

With a total of nine projects, at least one project is represented from all river types in the ecoregion “river types from the highlands” (Table 1). In the ecoregion “Northwest German Lowland” five surveys were answered. No project was from the river type 17. Two experts did not answer this question.

In 56% of the projects, an on-site inspection of the measure took place after the end of the project. In 25% of the cases, a regular inspection is carried out, but the intervals between the inspections vary from project to project. In 19% of the projects, no inspection took place at all.

The last question in this block refers to interventions in the soil according to a table published by Feldwisch (2012) with 23 potential measures affecting the soil. Apart from dike deactivation, all possible interventions were implemented at least once in the projects. Multiple responses were possible. The most frequent measures were the creation of a new watercourse (81%), the restructuring of the riverbed and the riparian area (69%) and the removal of revetments (63%). These are followed by measures regarding the creation (56%), upgrading (56%) or reactivation (38%) of floodplains. Except for one project, which included only one measure that could have an impact on the soil, the other projects carried out between two and ten of these measures.

Obstacles to soil protection in floodplain and river restoration projects

This section refers to the current status of implementation of soil protection in the river and floodplain restoration measures. In general, most of the experts rated soil protection in the project planning and implementation as important, or rather important (Fig. 1(a)). One person (6%) did not answer this question. Referring to their actual projects, most of the experts (69%) found soil protection in the implementation of their projects to be important or rather important. In general, in the project implementation the percentage is a little bit higher with 76%. For 25% of the experts, soil protection in the implementation of their projects is rather unimportant. In the planning of their projects up to 81% of the experts considered soil protection as important or rather important. For the planning of floodplain and river restoration projects in general, soil protection is seen as important or rather important in 69%. One person (6%) considered soil protection as unimportant for the

Table 1
River types and number of projects.

River Type	Name	Number of projects
River types of the Highlands		9
9	Siliceous, fine- to coarse material-rich Highland streams	3
9.1	Carbonaceous, fine- to coarse-material- rich Highland streams	1
9.2	Large rivers of the Highlands	3
10	Gravel-dominated streams	2
River types of the Northwest German Lowland		5
15	Sand- and loam dominated Lowland rivers	1
15_g	Large sand- and loam dominated Lowland rivers	2
17	Gravel dominated Lowland rivers	0
20	Sand-dominated streams	2
No answer		2

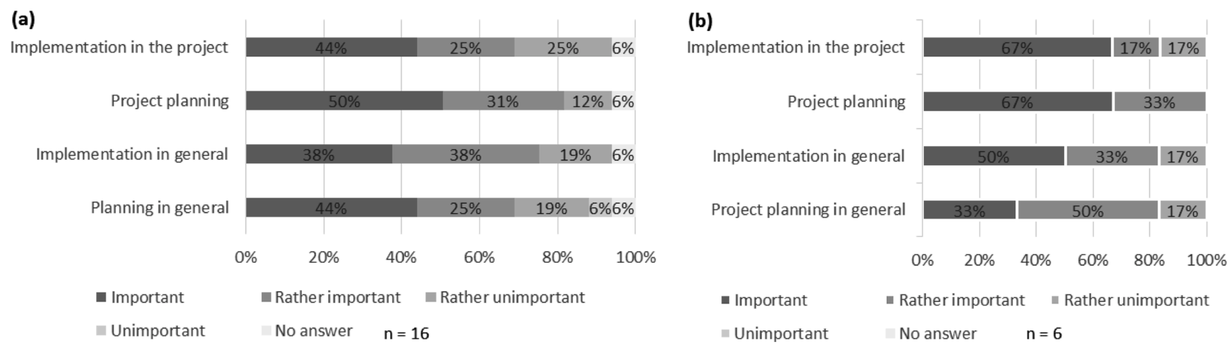

Fig. 1. (a) The importance of soil protection in the planning and implementation of specific projects and in general in the expert's perception; (b) the importance of soil protection in the planning and implementation in projects with Pedological Construction Supervision.

planning of such projects in general.

In total, six projects were supported by a Pedological Construction Supervision. It becomes clear that the range of responses is smaller for the projects with Pedological Construction Supervision than in the average answers (Fig. 1(b)). In these projects soils protection is considered more important, both in the actual project planning and implementation as well as in the general planning and implementation.

Considering the soil data that were used in the planning of the projects, none of the six specified categories was used in all of the projects (Fig. 2). In most cases (75%) the soil texture was taken into account in the planning, followed by soil contamination in 69%. Soil maps were used in 63% of the cases, and soil types considered in 50% of the projects. The moisture status of the soil was considered in 31% of the projects, and only 19% of the projects took the level of protection of the soils into account.

In contrast to the previous question, this question aims to determine how important soil data is considered to be in general, for the planning of river and floodplain restoration projects (Fig. 3). In the ranking, a similar order can be observed, but at 81% the consideration of soil contamination stands out. None of the experts considered the knowledge about soil contamination and soil texture as unimportant or rather unimportant. A relatively large number of experts have abstained on this question in most categories.

In the projects with Pedological Construction Supervision, more soil data was included in the planning of the projects (Fig. 4). In all projects, information on soil texture and soil types was used. Data on soil contamination and soil maps were considered in 83% of the projects. The level of protection of the soil was considered in 50% of the cases, while only 33% of the projects take into account the moisture of soils. However, this parameter can be deduced from the soil type by the soil experts performing the Pedological Construction Supervision.

Most of the experts (96%) believed that preliminary soil investigations are important or rather important for project planning. Thus, preliminary soil investigations were conducted in 14 out of 16 projects (88%). In the free comments section various experts explained that the main reason for preliminary soil investigations is the search for contaminated soil because this often results in increased costs. Consequently, by getting knowledge about the soils in advance, the financial costs of such a project can be better estimated.

Of the various concepts for construction supervision common in Germany, the Ecological Construction Supervision is perceived to be the most important in floodplain and river restoration projects, according to 94% of the experts (Fig. 5). Nevertheless, 69% also considered Pedological Construction Supervision as important or rather important. Half of the experts rated the Environmental Construction Supervision as important or rather important.

With reference to actual utilization, Ecological Construction Supervision, used in 42% of the projects was most frequent. Followed by Environmental Construction Supervision at 20%, and Pedological Construction Supervision at 19%. Other types of construction supervision were considered, for example Technical Construction Supervision or Archaeological Construction Supervision in 16% of the projects.

The Environmental Construction Supervision and the Ecological Construction Supervision are often used as synonyms. Nevertheless, they differ in their range of services: while the focus of the Ecological Construction Supervision is primarily on ecological aspects, the Environmental Construction Supervision also includes other environmental protection aspects like emission control and aspects of the German Environmental Damage Act (USchadG).

Support in planning and implementation in the form of handouts,

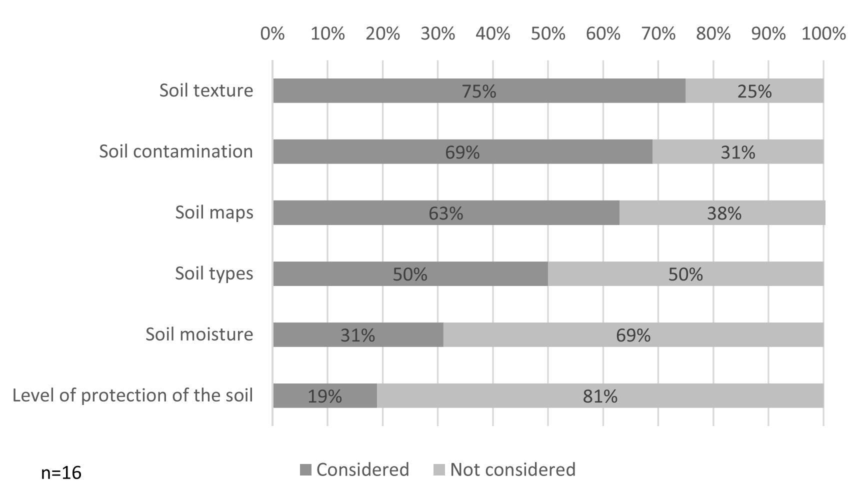

Fig. 2. Consideration of soil data in the project planning.

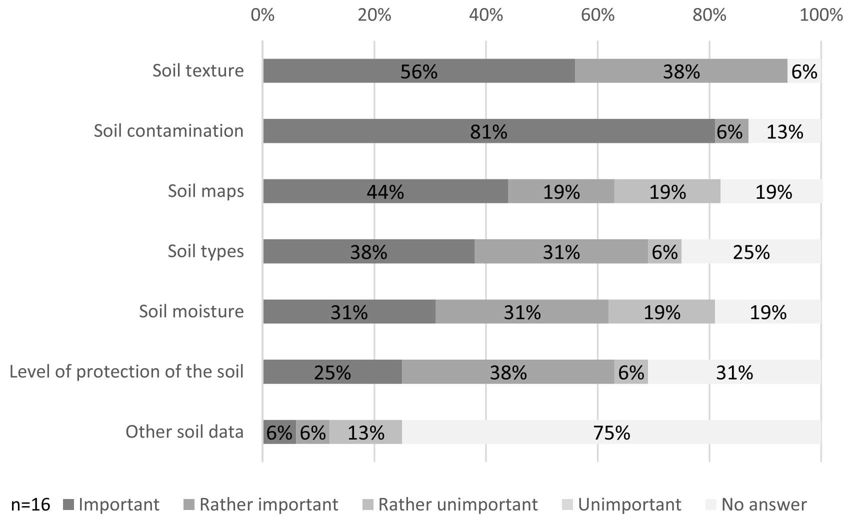

Fig. 3. Importance of soil data in the expert's projects.

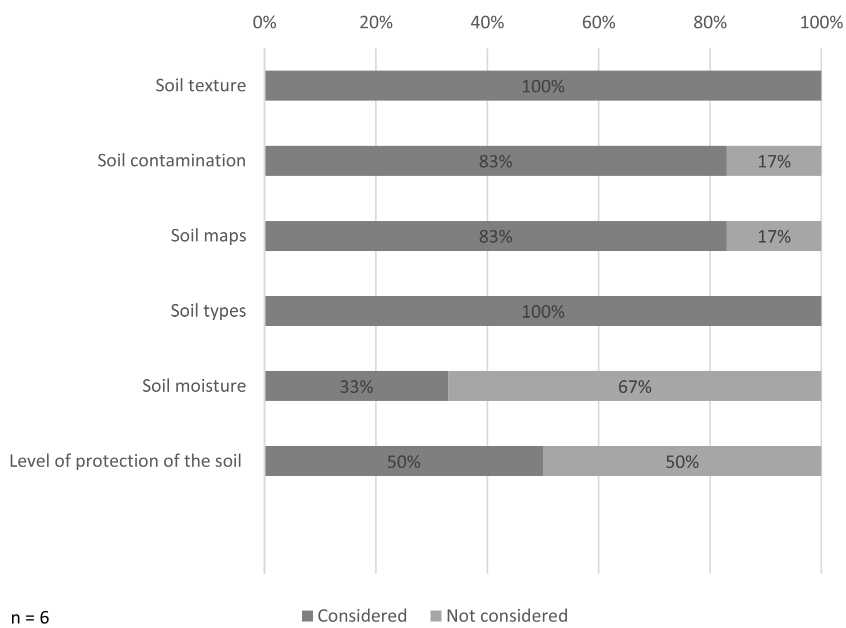

Fig. 4. Consideration of soil data from the projects with Pedological Construction Supervision.

leaflets, recommendations etc., was used in most of the projects (83%) provided by the federal state governments. Only 17% did not consider these possibilities. In 13% of the projects support from other federal states was used. Support from other countries (e.g., from Switzerland) or other industry sectors was not considered in any of the projects.

The last question of the survey related to the regular inspection of the measure after its completion. A quarter of the experts considered regular monitoring as important: 44% think regular inspection is rather important and as many as 13% say that this point is rather unimportant. One expert abstained.

Status quo of soil protection in floodplain and river restoration projects

This part of the survey dealt with the problems of soil protection in river and floodplain restoration projects and aims to identify the obstacles to soil protection in such projects. First, actual impacts on the soil in the projects were surveyed. Of the experts responding 21% stated that soil removal or soil excavation had taken place (Table 2).

In 18% of the projects soil was relocated and in 17% soil application took place. The soil was intensively driven in 17% and compacted in 11% of the cases. Riverbank erosion took place in 11% of the cases. The other impacts on the soil were very low in the projects.

The next question asked about information exchange with colleagues from other departments, with other experts or other persons in the projects, which took place in 63% of the projects. In 31% there was no exchange and 6% did not answer this question. In projects with Pedological Construction Supervision the percentage was even higher at 83%. In projects without PCS other experts were consulted in only 50% of the cases. Of all those who went into collegial exchange, 50% felt the exchange was (very) useful, 12% found the exchange was moderately useful, and the rest did not answer the question.

This was followed by a question about adverse impacts on the soil during the construction measure. 44% of the experts state that there has been no adverse impact on the soil during construction (Table 3).

One person added as a comment that such impact could, however, have happened unknowingly. In 25% of the projects the following adverse soil impacts have been assessed: driving on the soil when soil conditions were too wet, soil compaction, and driving on the soil outside

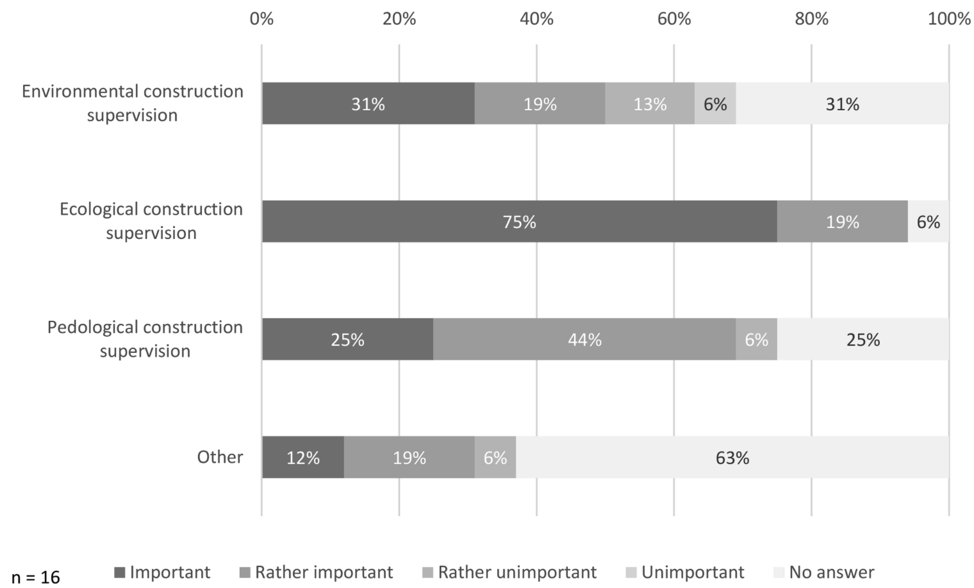

Fig. 5. Importance of the various construction supervision concepts in Germany in the perception of the experts.

Table 2
Impacts on the soil during the restoration measure [%].

Soil impact	Number of projects [%]
Soil removal/soil excavation	21
Soil relocation	18
Soil application	17
Intensive driving on the soil	14
Soil compaction	11
Riverbank erosion	11
Impairment of the soil's archive function	4
Pollutant discharge into the river from polluted sediments and floodplain soils	3
Pollutant deposition in the floodplain because of deposition of polluted sediments	1

Table 3
Adverse impacts on the soil during the construction measure [%].

Impact	Number of projects [%]
No adverse impact on the soil	44
Driving on the soil with too wet soil conditions	25
Soil compaction	25
Driving on the soil outside the marked paths	25
Incorrect storage of the soil material	6
No answer	0

of marked paths. In 6% of the cases the soil was stored incorrectly.

The last question in this block is about documented problems with the soil after completion of the construction measure. Here 56% of the experts indicate that (so far) no problems have occurred regarding the soil (Table 4).

Table 4
Documented problems with the soil after the end of the construction measure [%].

Problem with the soil	Number of projects [%]
No problems (so far)	56
Soil compaction	13
Waterlogging	6
Change of redox conditions	6
Damage of the soil structure	0
Pollutant release due to riverbank erosion	0
No answer	6

Compaction has been reported in 13% of the cases. Damage to the soil structure was not mentioned by the experts, although compaction goes along with damage to the soil structure. In 6%, the redox conditions have changed; moreover, waterlogging occurred in areas of the soil that are not naturally prone to waterlogging. Pollutant release due to riverbank erosion did not occur in any of the projects.

Qualitative survey

This section summarizes the results of the qualitative questions of the survey. The experts describe that some adverse impacts on the soil took place during the construction measures. They note that some of these impacts cannot be avoided during construction. Therefore, they say, a carefully planned construction site layout in advance, including passable, delineated paths and material storage areas, can counteract these adverse soil impacts.

However, most of the experts see an advantage in taking soil precautions and preventing possible difficulties from arising in the first place. Firstly, all project employees must be briefed by the construction management about soil protection. A PCS would be useful in providing advice and support about avoiding problems affecting the soil. General construction supervision is indispensable for checking whether the regulations are being complied with. The basis for the correct procedure during implementation of the measure is provided by legal regulations. In addition, it is emphasized by the experts that unexpected developments always could arise, which is why they see it as critical that all details should be specified in advance. They point out that sufficient opportunities should remain for planning changes.

Asking the experts about the need for changes regarding soil protection during restoration measures, the majority thought that there is still potential for improvement in many aspects. Some experts indicated that they would not change anything in their approach to soil protection in a new project. They base their opinion mainly on their own confidence in the correctness of applied and selected measures, and the support they received in soil protection during the implementation. The need for action is revealed by the fact that the connection between floodplain and river and its dynamics within the projects, is still insufficiently recognized and implemented. Another problem the experts see is that legal requirements are often not sufficiently implemented, for example, driving outside the designated paths on the construction site, or the proper disposal of contaminated soil. To minimize potentially harmful impacts on the soil, early coordination with soil protection authorities and long-term monitoring are seen as important measures and should be included early in the planning process. According to the experts interviewed the incentive to implement soil protection measures was largely stimulated by legal requirements or obligations in the approval procedure of the project. Secondary regulations of planning approval can require the inclusion of a PCS. One expert stated that there has been no incentive to integrate soil protection explicitly and that soil protection is always considered in their larger projects. In another case, the motivation to integrate soil protection came through the participation of an expert in a working group. If no soil protection measures have been considered so far, the survey indicates that the impulse should be given either by legal requirements or soil protection authorities.

As suggestions for the improvement of soil protection in river and floodplain restoration projects, the experts state that each project should be assessed individually regarding the necessary soil protection measures. In renaturation projects, numerous concerns (e.g., water, nature or soil protection, financial concerns) must be considered and weighed against each other. Therefore, it is essential to find a compromise between all those concerns. In this regard, cooperation between the two conflicting areas of water and soil protection is particularly important. Should soil damage be unavoidable, it should at least be minimized.

Six of the 16 experts explicitly want more support in dealing with soil protection. Among them are the experts from the project planning and the nature associations. They would like to see more project-related support from the authorities instead of the general citation of the legal paragraphs. They also state that in their experience authorities often don’t have the personnel resources for good guidance and on-site support. Some experts from the authorities, expressed the wish for more support in soil concerns, while six other experts state that they don’t need any further assistance in this regard and the remaining four abstained. The experts wish for more support above all from environmental authorities, soil protection authorities and the water management office.

The criticism of existing support is that the authorities often do not take a definite position and do not participate enough in the planning and implementation process. Another major problem area is the combination of different objectives, such as water management and soil protection. The fact that a compromise must be found between different perspectives is an obstacle that still has to be solved.

Only three experts are in favor of a legally required Pedological Construction Supervision in principle. One of the supporters is nevertheless skeptical, since the Pedological Construction Supervision negatively influences the project regarding cost and duration. It has also been suggested that Pedological Construction Supervision could already be prescribed by the licensing authorities of such projects.

However, most of the experts think that Pedological Construction Supervision shouldn’t be mandatory. A decision should be made for each project, for example based on the project scope, because decision-making could become more difficult as soon as more construction supervisors from different areas participate in the project.

Finally, the survey results emphasize that soil that is no longer needed should be allowed to be reused or recycled as completely and usefully as possible. The disposal of soil in landfills causes high costs which landowners often do not want to cover. In this way, pollutants may get into deeper soil layers and eventually reach the groundwater. Overall, the willingness to invest in renaturation projects depends on the ultimate benefits of the results for many of the cost bearers.

Discussion

The study reveals interesting insights on floodplain and river restoration projects, but the results need to be discussed in a broader context. The concept of Soil Security is ideal to connect various important aspects and results from the study with each other.

The results show that most of the projects studied had various impacts on the soil, for example through the creation of a new watercourse, or the restructuring of the riverbed and the riparian area, resulting in soil removal, soil relocation and other soil impacts. This goes along with an international trend in river and floodplain restoration projects with a focus on the channel morphology, resulting in major soil-moving activities (Palmer et al., 2014). This means that in the context of floodplain and river restoration projects, in many cases soil is somehow affected (Laub et al., 2013; Palmer et al., 2014) and should therefore also always be part of the planning and implementation measures. But the degree to which soil is included in the floodplain and river restoration projects varies considerably.

First, the biophysical characteristics of the floodplain soils need to be integrated in the projects. This corresponds with the **Capability** in the Soil Security concept. Floodplain soils may show distinctive characteristics, as they are at the interface between water and land, and are strongly influenced by the adjacent river (e.g., high susceptibility for compaction, high groundwater levels, high organic matter content, etc.) (Gerrard, 1987; Boettinger, 2005; Zausig et al., 2020; IUSS Working Group WRB 2022). The results of this survey indicate that most of the experts interviewed already consider soil as an important part of the planning and implementation of restoration projects. And in projects subject to a PCS the number of projects in which soil is considered important is even higher. Some soil data has been considered in all projects, although the kind and extent of the soil data considered differs between projects. A review of floodplain and river restoration projects has shown similar trends in projects all over the world. In many cases, only incomplete soil data has been considered in the projects. For example, only single physical or chemical parameters (like pH, texture etc.) have been analyzed which does not describe these special floodplain soils sufficiently (El Hourani and Broll, 2021). In this study of floodplain and river restoration projects one soil parameter stands out and is seen as extremely important by the experts in this survey: soil contamination. This aspect has also been highlighted in the context of preliminary soil examination. The experts interviewed highlight that this factor always influences the financial planning of the projects and can sometimes result in projects ultimately not being implemented because they are regarded as too expensive; especially when contaminated soil has to be disposed of as waste, due to high pollution values. Insufficient funding and conflicting interests between stakeholders have been identified as two of the major barriers for successful ecological restoration in Europe (Cortina-Segarra et al., 2021). Although floodplains are natural sinks for contaminants it is important to consider all aspects of the floodplain soils, their functions, and services and not only the contamination aspect (Zausig et al., 2020).

If the original biophysical characteristics of the soil are insufficiently assessed, this makes it difficult to evaluate changes in the capability after completion of the restoration measure. The shift of capability is described by the term **Condition**: Condition considers the deviation of soil attributes under different land-use managements (McBratney et al., 2014; Bennett et al., 2019). In the context of floodplain and river restoration projects, condition can refer to the situation before and after the restoration measure. Knowing if there has been a change in the soil attributes can be important in evaluating the success of the restoration measure and drawing the right links between the restoration project and the ecological changes (Hale et al., 2014; Morandi et al., 2014; Fisher et al., 2019; Zausig et al., 2020). Poor evaluation strategies often lead to wrong ecological conclusions, and the projects with the poorest evaluation strategies tend to draw the most positive conclusions about their projects (Morandi et al., 2014). If soil health is negatively impacted due to careless behavior during construction measures, this can lead to the failure of the ecological objectives of the restoration measure. Unhealthy soils cannot fulfill their functions and services to the same extent as healthy soils. If a soil is compacted for example, it can no longer properly fulfill its habitat function for plants and soil organisms, as air and water regimes are affected; infiltration of water is reduced which also leads to less flood protection. Reduced soil health can thus counteract the ecological objectives of restoration measures. Therefore, the exact knowledge of the parameters before and after the measure is important, to be able to correctly assess the condition – being positive or negative. Analysis of the expert's responses in this study indicates that a regular evaluation of the project measure is considered as important or rather important by many. Some experts admitted that they could not adequately assess impacts on soils after completion of the restoration measure, as there had been little or no monitoring activity during the project. Monitoring at the end of the restoration measure and especially of the soil parameters (capability) is a standard procedure in the PCS. In addition to the contamination aspect, soil compaction, erosion and soil mixing are also important control criteria. These aspects are assessed via soil parameters: To measure the compaction for example, first a visual examination of the soil and of the plant growth takes place. This can be accompanied by penetrometer measurements and determination of the bulk density. For erosion and soil mixing there are also defined soil parameters which are described in detail in BVB (2013). In this document methods and threshold values for the measurement of soil parameters are specified, and reference is made to the relevant DIN standards and ordinances. Bouma and Veerman (2022) stress the importance of threshold values to define good soil health and the development of simple methodology to measure soil parameters in the field. Cost-effective methods could also help to foster the acceptance of a PCS, as the PCS is considered too expensive by some experts.

The **Capital** of the soil in the context of floodplain restoration includes the numerous functions and services floodplain soils provide for nature and humans. Ecosystem Services can be assessed through various methods, mainly monetary or non-monetary (Podschun et al., 2018): Since river systems often extend over several countries, a monetary assessment may also differ between countries due to socioeconomic conditions (Chan et al., 2012; Perosa et al., 2021). In contrast, non-monetary approaches (especially quantitative approaches) can be compared easily amongst different countries as they use absolute values (Stäps et al., 2022). As an example, the River Ecosystem Service Index (RESI) a non-monetary, quantitative indicator approach has been developed to map ecosystem services explicitly of rivers and floodplains. This approach also uses soil as one important parameter (Podschun et al., 2018). Another approach to assess the capital of floodplains and their soils can be achieved via the United Nations Sustainable Development Goals (SDGs). These 17 goals, introduced by the United Nations in 2017, are the basis for peace and prosperity for people and the planet (United Nations, n.Y.). Floodplains and their soils contribute to various SDGs, like no poverty (SDG 1), zero hunger (SDG 2), good health and well-being (SDG 3), clean water and sanitation (SDG 6), sustainable cities and communities (SDG 11), responsible consumption and production (SDG 12), climate action (SDG13) and life on land (SDG 15) (Nolan et al., 2021; Smith et al., 2021; Ronchi et al., 2019; Bouma et al., 2019). Transdisciplinary approaches are now needed to link soil properties with ecosystem services, to quantify their effects on the SDGs (Keesstra et al., 2016). Dazzi and Lo Papa (2022) stress the importance of the economic value of the soils (capital) in achieving the SDGs and increasing soil awareness. They state that this might be an important aspect for politicians and administrators when considering soil aspects. The consistent assessment of the capital of the floodplain soils in floodplain and river restoration projects increases the awareness of all stakeholders of the importance of the soils in such projects.

These concepts also need to be integrated into the governance of the soil (**Codification**). In the context of river and floodplain restoration this governance comprises all legal regulations, legislations, laws, and other guidelines for the appropriate handling of floodplain soils. On the European level there is a compelling need to launch new legislation to achieve a binding legal framework to protect soils for future generations (Ronchi et al., 2019), similar to the Water Framework Directive. To date, there is no special legislation at EU level (nor in Germany) that addresses floodplain soils explicitly. Currently, soil legislation happens mainly at EU member state level, and varies amongst the countries (Ronchi et al., 2019). At EU level, soil legislation remains fragmented and is not sufficient either to address the current soil threats or to achieve the SDGs (Ronchi et al., 2019; Heuser, 2022). The European Green Deal with its various sub-strategies (EU Soil Strategy 2030 and EU Soil Health Law) is a first attempt to address the needs for a modern and effective new soil legislation following the final withdrawal of the Soil Framework Directive in 2014. Until now there has been a gap between the knowledge we have of soil threats and reduced soil health, and the degree of policy attention given to the soil. A gap that needs to be closed by the new soil legislation (Koch et al., 2013; Ronchi et al., 2019). The new and consistent soil legislation at EU level, hopefully leads to a situation similar to what the Water Framework Directive did for the European Waters; first, providing a legal and uniform framework for soil protection and second, bringing soil onto the agenda at all. The new legislation attempts at the European level, also support soil legislation approaches at member state level, like for example, the planned new edition of the German soil protection law. This approach will probably integrate many more aspects of soil protection at all levels in the new law, like aspects of climate protection, climate adaptation and the preservation of biodiversity. In total, the new law complements the current focus of the law from soil protection of follow-up care of contaminants with more precautionary approaches (BMUV, 2022a). Such attempts at member state level would be strengthened by a consistent and robust new EU legislation. Putting soil on the agenda of the European Union and of each member state would help to support soil protection in floodplain and river restoration projects. Many of the experts interviewed mentioned that the current soil legislation (in Germany) is complicated and that they would like to see more clarity in dealing with soil protection. Sometimes, soil is also seen simply as an additional task to consider, and as a burden during such projects, leading to conflict between various aspects of the projects (river protection, nature conservation, flood protection etc.).

Besides the soil legislation, an increased awareness of the soil and its needs would also help to better integrate soil protection in floodplain and river restoration projects. Large-scale awareness of soils has been identified as the basis for sustainable land management, and to achieve the SDGs (Visser et al., 2019). This aspect is described as **Connectivity** in the Soil Security concept. Connectivity aims at the knowledge about soil of all stakeholders and takes into account a social component (McBratney et al., 2014). The consideration of social aspects in restoration projects has also been shown to be relevant for the success of such projects (Visser et al., 2019; Arsénio et al., 2020; Farrell et al., 2021; Franceschinis et al., 2022; Mohan et al., 2022). Connectivity assumes that persons or societies that are connected with the soil and that have the appropriate knowledge, act more sustainably (McBratney et al., 2014; Eusse-Villa et al., 2022). Ideally, all persons involved in the floodplain and river restoration projects should be connected to the soil. That means that they are aware of the plentiful functions and services, and that they have the right knowledge about how to deal with the soil. In this regard, education and training possibilities for all stakeholders play a special role. It is important that there are soil experts on restoration sites with corresponding soil knowledge, and the demand for experts with soil knowledge is high (Havlin et al., 2010; Bosold et al., 2022). At this point, an active involvement of the soil science community seems useful, and training in awareness should already begin in the education of soil science students (Bouma et al., 2019). These soil experts can later act as multipliers for the soil's concern, strengthen the position of soil in such projects, and raise awareness of the soil by other stakeholders. A bottom-up approach with the involvement of all stakeholders in the whole process can also lead to more soil awareness in these groups. The collaboration of the different stakeholders in so-called living labs and the effective communication about successful projects ("lighthouses") has been shown to be a very successful concept for real-life transdisciplinary (Bouma, 2022; Bouma and Veerman, 2022).

Sustainable soil management is underpinned and strengthened by the new soil legislation at EU and member state level. In addition, special training courses are needed for soil science students, to enable successful river and floodplain restoration (Nolan et al., 2021). One example of such a training course is the Pedological Construction Supervision (PCS) in the German-speaking area. The course exists in two variants, one for practitioners and one for the staff of soil authorities. The course focuses on soil protection on construction sites, and includes soil protection from the beginning and planning stage of the projects, to the implementation and subsequent monitoring (BVB, 2013; Bosold et al., 2022). As floodplain and river restoration projects often result in major soil-moving activities and soil is impacted in many cases (Laub et al., 2013; Palmer et al., 2014), such projects can also be regarded as construction sites and PCS is transferable to these projects. In the projects reviewed, a PCS is already part of some of the projects and has led to a higher proportion of soil data being considered in the planning, more knowledge exchange between experts and consultation with other fields in these cases. The need for cross-disciplinary knowledge of experts for successful ecological restoration has also been highlighted by several authors (Keesstra et al., 2016; Fisher et al., 2019; Aronson et al., 2020; Edrisi and Abhilash, 2021; Nolan et al., 2021). Even though some of the experts interviewed do not think that a legally binding PCS is necessary, it can be a good way to implement soil protection in floodplain and river restoration projects and easily fulfill the legal requirements that come along with the new soil legislation on EU and member state levels.

The discussion shows that the Soil Security concept is very suitable to connect the different aspects of soil protection in floodplain and river restoration projects. Applying the Soil Security concept in this context could help to establish a holistic soil protection concept, covering all 5 dimensions. During the UN Decade on Ecosystem Restoration, with an increasing focus on restoration projects, it is also a great opportunity to finally prioritize soils in floodplain and river restoration projects and foster the use of the multiple and already available methods for soil protection, to tackle the great tasks of our time.

Conclusions

The Soil Security concept can be applied to floodplain and river restoration projects. It can provide a holistic approach to integrate various dimensions of soil protection in floodplain and river restoration projects, considering the 5 Cs: To date, Capability is assessed to a variable extent in floodplain and river restoration projects in Germany (e.g., focus on soil contamination; effects of physical disturbances of the soils were more or less neglected). Capability is the basis to efficiently assess the Condition. Regular monitoring of the soil parameters is essential; therefore, we strongly recommend the regular monitoring of the capability, to be able to evaluate possible (negative) impacts on the soils, as they might become clear only sometime after completion of the restoration measure. The Capital of (floodplain) soils is not easy to quantify, but its assessment would be very useful in the context of floodplain and river restoration projects. There are several options to quantify the Capital (e.g., RESI or SDGs), which could help raise awareness of soils and make their value visible for politicians and administrators. To date, heterogeneous and inadequate soil legislation at EU and member state level (e.g., in Germany) makes soil protection in floodplain and river restoration difficult for the restorers (codification). The new edition of the soil protection legislation in Germany, with a shift from follow-up care to more precautionary approaches for example, could contribute to improved soil protection in such projects. Finally, floodplain and river restoration projects would benefit from an increased soil awareness (Connectivity) of all stakeholders involved in the projects. This could be achieved through more education and training possibilities like the Pedological Construction Supervision.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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