land

Review

Soil Protection in Floodplains—A Review

Mariam El Hourani * and Gabriele Broll

Department of Soil Science and Agroecology, Institute of Geography, University of Osnabrueck, 49074 Osnabrueck, Germany; Gabriele.Broll@uni-osnabrueck.de
* Correspondence: mariam.elhourani@uni-osnabrueck.de

Abstract: Soils in floodplains and riparian zones provide important ecosystem functions and services. These ecosystems belong to the most threatened ecosystems worldwide. Therefore, the management of floodplains has changed from river control to the restoration of rivers and floodplains. However, restoration activities can also negatively impact soils in these areas. Thus, a detailed knowledge of the soils is needed to prevent detrimental soil changes. The aim of this review is therefore to assess the kind and extent of soil information used in research on floodplains and riparian zones. This article is based on a quantitative literature search. Soil information of 100 research articles was collected. Soil properties were divided into physical, chemical, biological, and detailed soil classification. Some kind of soil information like classification is used in 97 articles, but often there is no complete description of the soils and only single parameters are described. Physical soil properties are mentioned in 76 articles, chemical soil properties in 56 articles, biological soil properties in 21 articles, and a detailed soil classification is provided in 32 articles. It is recommended to integrate at least a minimum data set on soil information in all research conducted in floodplains and riparian zones. This minimum data set comprises soil types, coarse fragments, texture and structure of the soil, bulk density, pH, soil organic matter, water content, rooting depth, and calcium carbonate content. Additionally, the nutrient and/or pollution status might be a useful parameter.

Keywords: soil protection; restoration; floodplain; soil bioengineering

Citation: El Hourani, M.; Broll, G. Soil Protection in Floodplains—A Review. *Land* **2021**, *10*, 149. https://doi.org/10.3390/land10020149

Academic Editors: Chiara Piccini and Manuel López-Vicente

Received: 17 December 2020
Accepted: 29 January 2021
Published: 3 February 2021

1. Introduction

Floodplains and their soils are an important part of the river system and fulfil important ecological, economic, and social functions like natural flood protection, sustaining high biological diversity or filtering and storing water [1,2]. Floodplains can be regarded as hotspots for biogeochemical processes such as denitrification [3,4] or eutrophication [1]. Floodplains are regularly flooded by the adjacent river [5]. Thus, the lateral connection to the river is essential for the functioning of a floodplain [6]. The riparian zone is characterized as the zone between the low-water and the high-water mark [7,8]. Both represent ecotones at the transition between aquatic and terrestrial environments [6]. Riparian zones hence are the last point in the landscape where nutrients can be intercepted before they enter the rivers [9]. Often, the terms floodplain and riparian zone are treated as synonyms in the literature or are not clearly differentiated from each other. Floodplains do not only provide a wide range of ecosystem services, but also are one of the most threatened ecosystems in the world [2,10]. Today, many floodplains worldwide are degraded because of high hydromorphological and diffuse pollution pressures, dam building, diversion, or abstraction of water or clearing of land and cannot deliver the ecosystem services in the same extent as a natural floodplain [1,11,12]. Approximately 70–90% of Europe's floodplains are degraded [12]. The dynamic flow regime of the river is essential not only to the river functioning, but also to the ability of the floodplain to provide ecosystem services [11].

Soils in the floodplains and the riparian zone are strongly influenced by the adjacent river. These soils are often called alluvial soils as their physical, morphological, chemical, and mineralogical properties are influenced by the alluvial parent material derived from the river. The development of alluvial soils strongly depends on the flow regime [13]. Sediment transport and deposition are characteristic processes for the development of alluvial soils [14]. Recent alluvial soils are often classified into the reference soil group of Fluvisols in the world reference base for soil resources or into the order of Entisols (suborder Fluvents) in the US soil taxonomy [13,15,16]. Older alluvial soils can be transformed into multiple different soil types [13]. Fluvisols are characterized by fluvic material and can occur on any continent and in any climate zone. They occupy less than 350 million ha worldwide [15]. Naturally Fluvisols are fertile soils having been used by humans since the prehistoric times. Soils in the floodplain or riparian zone influenced by groundwater and showing classic gleyic properties can also be classified as Gleysols. These are soils that typically occupy low positions in the landscape with high groundwater tables and can also occur on any continents and in any climate zones. The parent material on which Gleysols develop can be a wide range of unconsolidated deposits, but often they also develop on fluvial, marine, or lacustrine deposits like Fluvisols [15]. Through their special characteristics these alluvial soils are able to provide information on past and present fluvial dynamics and ecosystem structure through their morphology [17,18].

In the past decades, floodplain management has changed from river control to the restoration of floodplains and rivers which can reduce the pressures and restore related functions and services [1,2,10,19–21]. In Europe, several directives like the Water Framework Directive (Directive 2000/60/EC), the Habitat and Birds Directives (Council Directive 92/43/EEC and Directive 2009/147/EC) or the Floods Directive (Directive 2007/60/EC) foster the restoration of river and floodplain ecosystems [22]. The decade of 2021–2030 is also assigned as the United Nations decade on ecosystem restoration. It emphasizes that nowadays there is still an urgent need to restore degraded ecosystems (https://www.decadeonrestoration.org/).

Restoration activities in floodplains and riparian zones, however, can also affect soils in these areas through the use of heavy machinery, resulting in soil compaction, or the disturbance and mixing of the soil [23–25]. These negative effects and disturbances can persist, at least for a decade [23,25]. Soil development is, compared to the changes in vegetation or hydrology, a slow process [26,27] which explains why soils would not recover within a relatively shorter period after the restoration impact [25]. The assessment of the positive or negative impacts of restoration on riparian and floodplain soils, is of major importance [28] as crucial ecosystem services and functions are associated with soils in this zone [29].

The aim of this review is therefore to assess if and how riparian soils and soil properties are addressed in the research on floodplain and river restoration and in the research on floodplains and riparian zones with direct implications to future restoration projects.

The objectives of this review are:

1. To give an overview on research in floodplains and riparian zones of the world with implication to restoration projects in the last 20 years;
2. To assess in which kind and to what extent soils are addressed in the research;
3. To recommend further research needs on soil protection in floodplains.

2. Materials and Methods

This literature review is based on the principles of Pickering and Byrne [30] and the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [31]. In July 2020 a literature research was performed in Scopus and Web of Science. As the search for the terms “soil protection” in combination with “floodplain restoration” or “river restoration” resulted in only 12 or 10 articles, respectively, a broader understanding of soil protection had to be applied. In a first search article titles, keywords, and abstracts were searched for the terms soil, protection, river or floodplain, restoration, or construction and additionally water framework directive or WFD. A second search in the same databases in article titles, keywords, and abstracts with the terms soil, restoration, and riparian zone was performed. The review should cover all aspects of soil protection in floodplains and riparian zones and hence the search terms have not been further specified. The search was limited to literature published between the years 2000 and 2020 to focus on activities since the implementation of the Water Framework Directive in 2000. The results of the search are shown in a PRISMA flow diagram (Figure 1).

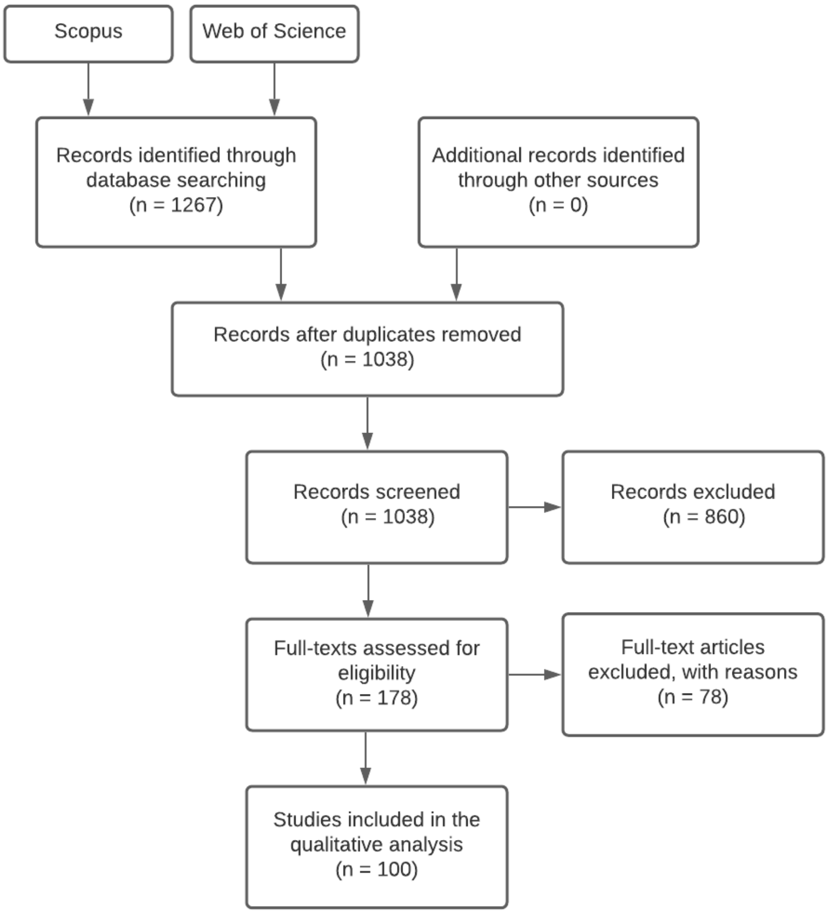

Figure 1. Flow diagram of the quantitative literature research performed in July 2020 (diagram adapted from Moher et al. [31]).

After duplicates were removed the search returned 1038 records. These articles were screened by abstract and 860 were excluded. Only journal articles were included. Books and conference proceedings were excluded from the beginning. Articles were excluded if the study area was different from rivers, streams, floodplains, or riverine/riparian wetlands. Water reservoirs, wetlands with no further specification (e.g., as riparian wetland) and artificial wetlands (e.g., treatment wetlands), coastal areas (like mangroves), and lakes were not considered for this review. Articles only concerning other topics like vegetation or forest growth, seedbanks, fish productivity, the functioning of a special geomaterial or geosynthetic, a construction work in a place different than a floodplain or river, landfills, etc., and no direct link to soil and soil protection were also excluded. The spatial scale was set to the floodplain or riparian zone. No restrictions were made to the geographic or climatic region. Articles at the spatial scale of river basins or watersheds and no direct reference to the soils in the riparian zone were also excluded. Only research articles fully written in English were considered for this review. This resulted in 178 full-text articles which were assessed for eligibility. Another 78 articles did not meet the criteria mentioned above. Finally, 100 full-text articles were included in the qualitative analysis.

The 100 articles were scanned for study region, year, and available soil information in the research. The soil information was grouped into categories including soil properties (physical, chemical, and biological), detailed soil classification, other type of classification like alluvial soils, and other soil information like the use of soil maps (Appendix A Table A1).

3. Results

3.1. Overview on Research in Floodplains and Riparian Zones of the World

Research on soil protection was conducted on every continent or geographic region, respectively, with the exception of Antarctica (Table 1). Most research (44 published articles) focusses on soil protection in floodplains and riparian zones in North America. In second place, 25 articles have been published about study sites in Europe. In one article research was conducted in Europe and North America. Then, 12 articles focused on research in Asia, 12 in Oceania, four in South America, and one in Africa. In three articles the geographic region was not specified, for example when research focused on models or frameworks without the need of a special study area.

Table 1. Number of articles on soil protection in floodplains or riparian zones per geographic region.

Africa	Asia	Europe	North America	South America	Oceania [2]	Not Specified	Total
1	12	25 [1]	44 [1]	4	12	3	100

[1] One article covered study sites in Europe and North America. [2] Oceania here only comprises Australia and New Zealand. For a detailed classification of the continents c.f. the United Nations definitions on geographic regions (https://unstats.un.org/unsd/methodology/m49/).

In total, research was conducted in over 24 different countries; half of them are in Europe. In most countries less than four studies have been realized. Most studies were carried out in the USA, followed by Australia with 11 studies and China with eight. Five studies were realized in Switzerland (Table 2). One article did not restrict the research to a specific country but focused on the whole Alpine area [32]. Studies in the USA were conducted in 22 different states.

Table 2. Number of study sites per country. Only countries with more than four studies are considered in this table.

USA	Australia	China	Switzerland
41	11	8	5

Regarding the climate zones after Schultz [33] approximately 50% of the articles covered study sites in the midlatitudes. Over 40% were carried out in the subtropics and dry tropics. In the boreal zone 2% of the studies were realized. In the humid tropics 3% of the studies were realized. In 2% of the studies no climate region could be assigned.

The number of articles published per year between 2000 and 2020 shows that only about one-third (33 articles) of the 100 articles has been published in the first decade between 2000 and 2010 (Figure 2). More than two-thirds of the considered papers have been published in the second decade between 2010 and July 2020 (67 articles), indicating an increasing interest in this topic. Most papers were published in 2017 and 2019 with 10 and nine papers each year.

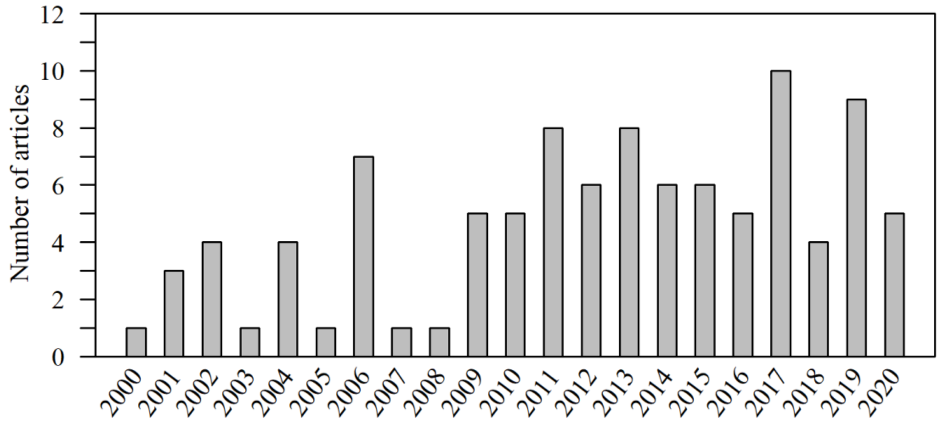

Figure 2. Number of articles on research on floodplains and riparian zones published each year between 2000 and 2020 (in 2020 until July).

Methods used over the period considered did not change significantly over time. Most research was done by field work (approx. 74%), e.g., soil surveys, field mapping, field experiments, and sampling. Laboratory experiments were carried out in about 10% of the studies. About 16% used models for the research, e.g., GIS-based models. Most studies included statistical analysis. Some studies used combined methods, e.g., field work and modeling.

3.2. *Soil Information in the Articles on Soil Properties*

Soil information in the articles was divided into physical, chemical, and biological soil properties, soil classification, and other soil information (Table 3). Soil information is vastly used in the examined research articles. Only three articles did not mention any soil information. In the remaining articles soil information is used to a different extent. A detailed table with the parameters of each soil information category is provided in the Appendix A (Table A1).

Table 3. Number of articles per soil information category (chemical, physical, biological properties, soil classification, other soil information, and no soil information).

Physical Properties	Chemical Properties	Biological Properties	Detailed Classification	Other Soil Classification	Other Soil Information	No Soil Information
76	56	21	32	6	9	3

In 76 articles some kind of physical soil parameters were used either to describe the study region or were investigated during the study. Physical soil parameters described by the different authors mainly contained classical soil physical parameters like texture and other descriptions of particle sizes and particle contents (e.g., fine material or coarse elements), electrical conductivity, porosity, soil temperature, or (dry) bulk density. In many cases soil parameters concerning the water household of soils like soil moisture content, (saturated) hydraulic conductivity, water holding capacity, infiltration, permeability, or field capacity are used, too. Some authors described more general parameters like the drainage situation or hydric conditions of the sites, but did not go into more detail. Other physical parameters mentioned were the pore-water pressure, the Atterberg limits, the specific gravity of the soil, (effective) cohesion, soil erodibility or an erosion coefficient, shear strength or shear stress, the (internal) friction angle, the van Genuchten parameters, and the rooting zone.

Chemical soil parameters were mentioned in 56 articles. Soil chemical parameters can be divided into several categories. In many articles nutrients were assessed, with focus on inorganic nitrogen (N) forms (NO_3^-, NO_2^-, NH_4^+, N_2O, total N), different phosphorus (P) speciations (e.g., plant available P, soluble reactive P, total P) and potassium (K) (e.g., total K, plant available K). Despite being nutrients, especially nitrogen and phosphorus are seen as non-point source pollutants, too. Other contaminants investigated are (heavy) metals like Cd, Pb, Hg, Zn, Cr, Cu, and others. In one paper organo-chlorine pesticides were examined. Another important soil chemistry category is soil organic matter (SOM). Here, different forms and types of SOM were addressed, like total carbon, inorganic and organic carbon, recalcitrant organic carbon (ROC), refractory index for carbon (RIC), or coarse particular organic matter (CPOM). Other parameters assessed were pH, salinity, $CaCO_3$, C/N, and isotopic ratios of C and N. One article mentioned the fertility of the soils investigated, but did not go further into detail.

Soil biological parameters were considered in 21 articles, containing data on soil organisms and processes driven by these inhabitants. In the research, soil invertebrates, soil microbial community structure (e.g., denitrifier and ammonium oxidizer density), and microbial number, species traits, operational taxonomic units and phylogenetic diversity, soil enzyme activity, denitrification enzyme activity (DEA), and actual denitrification were addressed. Other parameters were net potential nitrification, net potential N mineralization, potential mineralizable N, potential denitrification (rate), potential C mineralization, and microbial biomass C. Besides soil invertebrates and microorganisms, also root parameters, like root density, total belowground plant biomass, and root exudates, were examined. One article mentioned general biological activity features, but did not provide more details.

Some kind of soil classification/taxonomy is mentioned in 38 articles, whereas it has to be differentiated between a detailed classification from a common classification system or another soil description. Detailed soil description is provided in roughly one-third of the considered articles for this review (32 articles) and comprises descriptions on soil series, soil associations, soil types, soil map units, or soil orders based on the US Soil Taxonomy, the WRB, the Australian classification system, the French classification system, and others. In most articles these parameters are mentioned in detail (Which soil types? Which soil series?), but in few articles it is only mentioned that soil map units for example are used, but not which ones. In the remaining six articles soils are described more in general, for example as alluvial or hydric soils, but do not classify the soils in a common pedological classification system.

In the 32 articles that provide a detailed soil classification it is interesting in which combination and to which extent soil classification is combined with soil physical, chemical, and biological parameters (Table 4).

Table 4. Combination of physical, chemical, and biological soil properties in the 32 articles that provide a detailed soil classification [number of articles]. Articles that provide other soil information were not considered.

Physical + Chemical + Biological Properties + Classification	Physical + Chemical + Properties + Classification	Physical Properties + Classification	Chemical Properties + Classification	Biological Properties + Classification	Classification Only
6	12	5	3	0	6

Only six articles consider physical, chemical, and biological soil properties in combination with a detailed soil classification. Approximately one-third (12 articles) additionally mention soil physical and chemical parameters in their research. Five articles provide physical soil properties and three articles chemical soil properties in a combination with a detailed soil classification. Additional soil biological properties without chemical or physical properties were not covered in the research. Six articles provided a detailed soil classification only.

Good examples of the provision and use of soil information are mostly those articles that explicitly address soil properties in their research. For example, to describe the morphology of riparian soils in a restored floodplain in Switzerland as a restoration monitoring measure, Fournier et al. [34] provide not only detailed soil taxonomy, but also basic soil physical (texture, coarse soil), soil chemical (organic matter content and type, hydromorphological features), and soil biological parameters (root density and general biological activity features). In a comparison of the effects of different stream restoration practices (designed channel restoration vs. ecological buffer restoration) on riparian soils, beside USDA soil map units, the soil organic matter content, bulk density, soil moisture, texture, and root biomass were used and compared [25]. Other examples are the studies of Kauffman et al. [35], Clement et al. [36], Smith et al. [37], and Sutton-Grier et al. [38] which all provide soil information from all categories in their research.

In the 68 articles that do not provide a detailed soil description from a common soil classification, 11 articles, however, provide information on soil physical, soil chemical, and soil biological properties (Table 5).

Table 5. Combination of physical, chemical, and biological soil properties in the 68 articles that do not provide a detailed soil classification [number of articles].

Physical + Chemical + Biological Properties	Physical + Chemical + Properties	Physical + Biological Properties	Chemical + Biological Properties	Biological Properties Only	Chemical Properties Only	Physical Properties Only
11	16	3	1	0	7	24 [1]

[1] 15 out of the 24 covered engineering topics.

In 16 articles a combination of soil physical and soil chemical parameters is used. Soil physical parameters in combination with soil biological parameters were covered in three articles. Soil chemical parameters and soil biological parameters have been combined in one article only. If only one soil property was investigated or mentioned, most articles (24) provided information on soil physical parameters only, seven on soil chemical parameters only. Only soil biological parameters were used in none of the reviewed articles. Fifteen out of the 24 articles which provide soil physical parameters covered engineering topics only.

Soil information that could not be classified into the before mentioned categories is used in nine articles. These data comprise information on the use of soil maps or soil databases for example, the number and lower boundary of the soil layers or information on soil morphology (soil typicality, dynamism, and diversity). In some cases, soil properties that are taken from the maps or databases are further specified, but in other articles there is no further information on the kind of soil properties (chemical, physical, biological) or soil taxonomy.

3.3. Information on Soils in Articles in Connection with Engineering and Land Management

In total, 18 articles covered engineering topics, like soil bioengineering, river bank stability, or erosion control which can also be understood as some kind of soil protection. In these articles physical soil properties are considered only, e.g., shear strength, cohesion, texture or hydraulic conductivity. In the engineering articles neither soil chemical properties nor soil biological properties were used. None of the articles provided a detailed soil classification. One article considers additional soil biological properties (root system and root biomass) [39].

Another 32 articles deal with land management and land use, restoration planning, and the evaluation of restoration efficiency. In this category no clear pattern of the use of soil information is observable. Chemical and physical soil properties are described in the same extent in the articles as detailed soil classification (16, 24 and 16 articles, respectively). Soil biological properties play a minor role and are mentioned in six articles only. The provision of soil data differs between the 32 articles as few articles provide chemical, physical, biological soil properties in combination with a detailed soil classification (three articles), most do mention only parts of the different soil data types in a variable proportion.

4. Research Needs on Soil Protection in Floodplains

The results in Section 3.1 show that research on floodplains and riparian zones is not evenly distributed worldwide. Most research in the regarded period was conducted in North America and Europe, providing a broad base of knowledge on restoration of floodplains and the riparian zones in these areas. Other regions like Oceania, South America, Asia, and Africa are underrepresented in the research which leads to a lack of knowledge not only on restoration in riparian zones and floodplains, but also on soil information in these regions. More research in these regions of the world is highly recommended. When regarding the countries in which research on the individual continents is conducted it becomes clear that research mostly concentrates on single countries like the USA, Australia, Brazil, and China. The number of articles published on floodplain and riparian zone research was not distributed evenly over the two decades considered in this review. With two-thirds of the articles published in the second half of the reviewed period this shows the increasing concern and importance of research in the floodplains and riparian zones.

To protect soils and to interpret results of the research in the soil context it is important to know detailed properties of the regarded soils. Soil properties are described in most reviewed articles, but the extent of the provision and description of the soil properties varies considerably. Soil properties are important indicators when evaluating the soil quality and assessing soil functions [40]. Basically, soil quality is the capacity of a soil to function [41]. Soil quality depends on soil inherent and dynamic properties. Inherent properties are mostly influenced by the soil-forming factors (e.g., parent material, topography, time). Dynamic properties are influenced by human management and natural disturbances (e.g., land use or the construction of buildings or roads). Typical inherent soil properties are the soil texture or the drainage class. Management-dependent soil properties comprise among others the organic matter content, infiltration, biological activity, or soil fertility. The different soil properties can interact and limit other soil properties. Finally, the dynamic soil properties provide information about the ability of a soil to provide ecological functions and services [40]. Indicators for soil quality are traditionally divided into soil physical, soil chemical, and soil biological parameters [40,42]. In the reviewed articles over 75% provide information on soil physical parameters and hence information on the soil hydrologic status, on the availability of nutrients, on aeration, limitations on root growth, or the ability to withstand physical disturbances [40,42]. This information on soil physical parameters is very important for soil protection. Although not every article contains the same physical parameters, basic information on texture or particle sizes and soil moisture are given in most articles. Chemical parameters, mentioned in over 50% of the reviewed articles, are important to evaluate nutrient availability, water quality, buffer capacity, or the mobility of contaminants. Soil biological parameters, like abundance and biomass of soil organisms and their byproducts can also serve as an indicator for a functioning soil [42]. Biological soil parameters are assessed only in about 20% of the articles. It can be summarized that in current research in floodplain and riparian zones soil physical properties, chemical properties, and biological properties are used. There is a lack of information, especially on soil chemical and soil biological parameters. Both parameters can provide important insights in soil functioning and the reaction of the soils to certain conditions.

A detailed description from a common soil classification system like the WRB, the US soil taxonomy or a national classification system can be very informative not only for soil scientists. Soil classification systems are based on soil properties that are defined in diagnostic horizons, properties, and materials [15]. Therefore, when providing a detailed soil description from a common soil classification system, a lot of information on soil physical, soil chemical, and soil biological properties can be derived from using this classification. This information is missing, however, in about two-thirds of the reviewed literature. In these articles that do not provide a detailed soil description from a common soil classification system the majority of the authors though provide additional information on physical, chemical, and biological soil properties or combinations of these properties. The group of the articles with only physical soil data described mostly comprises articles dealing with engineering topics. In this group, except for one article that mentions some soil biological characteristics [39], soil is characterized by the physical characteristics only while other parameters like chemical or biological parameters are not considered. In this field, soil seems to be a granular medium only, serving as a building material, not as an important ecosystem compartment. But even if the physical and geotechnical properties of soils are most important for engineering purposes, a pedologicalview of soils, integrating some basic information on soil classification, on chemical and biological properties, might be valuable for engineers, too. As engineering measures usually comprise the use of (heavy) machinery, these measures can also be considered as a kind of construction work. This usually implies that the floodplain and riparian soils, adjacent to the riverbank or engineering site, are affected by these measures, too. Therefore, at least a minimum dataset on the soils of the whole site should be considered in projects, working in floodplains and riparian zones.

Other, more general, soil descriptions like the term "alluvial soils" for example, can give only general information on the soil development and on-site characteristics, but do not provide detailed information on the soil properties. As the physical, morphological, chemical, and mineralogical properties of these soils are strongly influenced by the alluvial parent material coming from the river, the soil characteristics, e.g., the soil texture and the related properties, can vary considerably [13]. In contrast, when a soil is classified within a common classification system, for example as a Gleysol (WRB), it is obvious that this soil must be saturated with groundwater long enough to develop these gleyic properties [15]. In the WRB, additional information on the soils and their properties can be deduced from the principal and supplementary qualifiers, such as the presence of an organic surface layer (qualifier: histic) or non-cemented secondary carbonates accumulated (qualifier: calcaric). Information on organic horizons or layers or waterlogging conditions due to high groundwater tables in floodplains and riparian zones are very valuable as especially these soils are highly susceptible to compaction for example [43]. So even if there is no additional information on physical, chemical, or biological soil properties, from a detailed soil description many soil characteristics can be deduced.

If a detailed investigation and description of the soils and their characteristics of the study sites is not possible there are other opportunities that should be considered to assess at least basic soil information of the site. For most regions of the world free soil information is available online from different organizations. A compendium of available data worldwide and for specific regions has been provided by ISRIC, the International Soil Reference and Information Centre for example [44]. They also maintain other useful sites and services like the World Soil Information Service (WoSIS) [45] and the SoilGrids platform [46] which can be helpful to consider.

As the results show, soil information is available in the large majority of the research papers, but it becomes also clear that in most cases soil information is incomplete or very specific only. To protect soils in floodplains and riparian zones, especially in the context of restoration works, a more pedological view of soils is necessary. This would not only be important for restoration projects directly, but also for all research in floodplains and riparian zones with the objective to contribute to restoration projects, for example in the prioritization of restoration areas.

Restoration projects impact soils in floodplains and riparian zones [25] and can therefore often be regarded as construction works. In recent years, soil protection on construction sites has become more and more important, for example in Switzerland or Germany. Known as "Bodenkundliche Baubegleitung" in the German-speaking area, it aims to protect soils from physical disturbance and contamination prior to and during construction. This means that after finishing the construction, the soil should be able to fulfil its natural functions again [47,48]. Detrimental soil changes that can occur on construction sites comprise soil compaction, erosion and discharge of substances, contamination, mixing of different soil substrates, and mixing of natural soil substrate with technogenic materials [48]. The soil protection on construction sites concept has not been developed for restoration projects, but as many restoration projects are comparable to construction sites, this concept is also applicable to restoration projects.

Soil protection on construction sites is not only applied during the construction works, but also prior to the construction in the planning process and is also involved post-construction in the monitoring and documentation of the project [47,48]. The lack of sound knowledge about soils has been identified as one of the factors hampering effective ecological restoration [49]. In the soil protection on construction sites concept various soil information is assessed for planning the construction work and appropriate soil protection measures during construction. This soil information comprises information on the soil types and their special characteristics (e.g., susceptibility to compaction or organic soils), coarse fragments, texture and structure of the soil, bulk density, pH, soil organic matter content, water content, rooting depth, and calcium carbonate content [47,48]. This soil information could be applied as a minimum dataset on soils in all research in floodplains and riparian zones and in restoration projects. Additionally, the nutrient and/or pollution status of the soil might be a useful parameter to be considered. The parameters proposed for the minimum soil data set contain stable and dynamic parameters. For dynamic parameters a continuous monitoring program might be useful. If not, many dynamic parameters like the physiological rooting depth for example can be deduced from easy to assess parameters like soil depth and soil texture. Also in the USDA stream restoration handbook [50] it is recommended to obtain background information on the sites, i.e., about soils. In general, to avoid detrimental soil changes many parts of the soil protection on construction sites concept could be easily integrated in the protocols for river, floodplain or riparian buffer restoration projects, as well as in soil bioengineering practices. In soil bioengineering practices there is great potential to integrate this minimum soil data set and soil protection measures during construction. Rey et al. [51] highlight the importance of the incorporation of current findings of the research in geosciences, for example soil science, in soil bioengineering practices. Further, scientist and practitioners should cooperate and exchange current issues and knowledge.

5. Conclusions

1. Research on floodplains and riparian zones of the world is not distributed evenly over the different continents, with the majority of research in this area conducted in North America, especially in the USA. The research on floodplains and riparian zones is also not distributed evenly over the time covered in this review with two-thirds of the research published in the second decade between 2010 and 2020.
2. Soils are somehow addressed in most articles, but the kind and extent of provided soil information varies significantly between the articles. Mostly physical soil information is provided, followed by chemical soil information. Only one-fifth provides soil biological information. One-third provides a detailed soil description from a common classification system. Soil information in the field of engineering is limited to physical data only.
3. Soils are addressed in the majority of the research, but soil information is often incomplete from a soil scientists' view. It is recommended to integrate at least a minimum data set on soil information in all research conducted in floodplains and riparian zones. This minimum data set comprises soil data used in the soil protection on construction sites concept: soil types and associated special characteristics (e.g., susceptibility to compaction), coarse fragments, texture and structure of the soil, bulk density, pH, soil organic matter content, water content, rooting depth, and calcium carbonate content. Additionally, the nutrient and/or pollution status might be a useful parameter. Further, at least the use of regional soil databases can give important information on the soils in the study area, if field work is not possible.

Author Contributions: Conceptualization, M.E.H. and G.B.; methodology, M.E.H., formal analysis, M.E.H.; writing—original draft preparation, M.E.H., writing—review and editing, M.E.H., visual-

ization, M.E.H., supervision, G.B.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study is available in Appendix A Table A1.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

As	Arsenic
ASC	Australian Soil Classification System
C	Carbon
$CaCO_3$	Calcium carbonate
Cd	Cadmium
C/N	Carbon/nitrogen ratio
CPOM	Coarse particular organic matter
Cr	Chromium
Cu	Copper
DEA	Denitrification enzyme activity
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
DON	Dissolved organic nitrogen
EC	Electrical conductivity
Fe	Iron
Hg	Mercury
IC	Inorganic carbon
K	Potassium
N	Nitrogen
Ni	Nickel
NO_3^-	Nitrate
NO_3^--N	Nitrate nitrogen
NO_2^-	Nitrite
NH_4^+	Ammonium
NH_4^+-N	Ammonia nitrogen
N_2O	Nitrous oxide
NO	Nitric oxide
NZG	New Zealand Soil Classification
OC	Organic carbon
OM	Organic matter
P	Phosphorus
PB	Lead
PO_4^{3-}	Phosphate
RIC	Refractory index for carbon
ROC	Recalcitrant organic carbon
RO	Réferentiel Pédologique (=French Soil Classification)

S	Sulfur
Sb	Antimony
SiBCS	Sistema Brasileiro de Clasifição de Solos (=Brazilian Soil Classification System)
Sn	Tin
SOC	Soil organic carbon
SOM	Soil organic matter
SRP	Soluble reactive P
TC	Total carbon
TDC	Total dissolved carbon
TDN	Total dissolved nitrogen
TBGB	Total belowground biomass
TK	Total potassium
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorus
V	Vanadium
WRB	World Reference Base for Soil Resources
Zn	Zinc

Appendix A

Table A1. Articles selected for this review, continent, country, and soil information categories.

Source	#Article	Continent	Country	Category	Chemical Properties	Physical Properties	Biological Properties	Detailed Classification	Other Classification	Other Soil Data
Agouridis et al. 2005	[52]	North America	USA, Kentucky	Management	-	-	-	Hagerstown (Fine, mixed, mesic Typic Hapludalf); McAfee (Fine, mixed, mesic Mollic Hapludalf); Woolper (Fine, mixed, mesic Typic Argiudoll)	-	-
Amezketa & del Valle de Lersundi 2008	[53]	Europe	Spain	Management	OM, $CaCO_3$, salinity	Texture, moisture, temperature, EC	-	Loamy-skeletal, mixed, mesic, Aridic Ustorthent; Coarse-loamy, mixed, mesic Aridic Ustifluvent; Fine-salty, mixed, mesic, Aridic Ustifluvents; Entisols	-	-
Andrews et al. 2011	[54]	North America	USA, Kentucky	Other	Fertility	Permeability, water holding capacity, rooting zone	-	Fine-loamy, mixed, mesic Dystric Fluventic Eutrochrepts (USDA 1996)	-	-
Anstead et al. 2012	[55]	Europe	UK	Engineering	-	Cohesion, texture	-	-	-	-
Asghari & Cavagnaro 2011	[56]	Oceania	Australia	Other	pH, plant available P, TC, TN	Texture	-	-	-	-
Atkinson & Lake 2020	[57]	North America	USA, Texas	Management	-	Erodibility	-	-	-	-
Bariteau et al. 2013	[58]	North America	Canada	Engineering	-	Texture	-	-	-	-
Beauchamp et al. 2015	[59]	North America	USA, Maryland	Management	OM, pH, C/N, plant available macronutrients and micronutrients	Texture	-	-	-	-
Bedison et al. 2013	[60]	North America	USA, New Jersey	Other	Mottling	Texture, drainage	-	Mesic Entisols; Histosols; Inceptisols	-	-
Bissels et al. 2004	[61]	Europe	Germany	Management	Plant available P and K, TN, TC, $CaCO_3$, OM, C/N	Texture	-	-	Alluvial soils	-
Botero-Acosta et al. 2017	[62]	North America	USA, Oklahoma	Engineering	-	Water content, field capacity, wilting point, saturated hydraulic conductivity	-	-	-	STATSGO soil map (soil types); Soil Characterization Database (physical soil properties)
Brovelli et al. 2012	[63]	n.a.	n.a.	Other	Various (not further specified)	Various (not further specified)	Various (not further specified)	-	-	-
Buchanan et al. 2012	[64]	North America	USA, New York	Management	-	Erodibility, texture	-	-	-	-
Burger et al. 2010	[9]	Oceania	Australia	Management	NO_3^-, NO_2^-, NH_4^+, plant available P, EC, pH, TC, TN	-	-	Grey, Yellow, and Brown Sodosols and Chromosols (ASC 1996)	-	-
Buzhdygan et al. 2016	[65]	Asia	Ukraine	Other	SOC, pH, TN	Bulk density	-	-	-	-
Cabezas & Comín 2010	[66]	Europe	Spain	Other	TOC, TN, C/N, RIC, ROC	Bulk density	-	-	-	-
Clement et al. 2003	[36]	Europe	France	Other	Hydromorphological features, OM, pH	Texture, bulk density	Denitrification activity, roots	Fine silty-clay loam, mixed, mesic Typic Haplaquoll (USDA 1990)	-	-

Table A1. *Cont.*

Source	#Article	Continent	Country	Category	Chemical Properties	Physical Properties	Biological Properties	Detailed Classification	Other Classification	Other Soil Data
Das 2016	[67]	Asia	India	Engineering	-	Shear strength, dry density, Atterberg limits, specific gravity, texture	-	-	-	-
Davis et al. 2006	[68]	North America	USA, Nebraska	Other	OM, TN, TK, TP, pH	Temperature, moisture, texture	Soil invertebrates	-	-	Groundwater level
De Mello et al. 2017	[69]	South America	Brazil	Management	-	Bulk density, available water capacity, saturated hydraulic conductivity	-	SiBCS (2018) (WRB 2015): Gleissolos (Gleysols); Latossolos Vermelho (Ferralsols); Latossolos Vermelho-Amarelo (Ferralsols); Neosolos Regolíticos (Regosols); Neossolos Flúvicos (Fluvisols); Cambissolos (Cambisols)	-	Number of layers, lower boundary of layers
Del Tánago & de Jalón 2006	[70]	n.a.	n.a.	Management	-	Permeability	-	-	-	-
Dhondt et al. 2006	[71]	Europe	Belgium	Other	OC, TN, IC, pH, N_2O fluxes	Texture	DEA	-	-	-
Dietrich et al. 2014	[28]	Europe	Sweden	Management	OM, mass fraction of C and N, isotopic ratios ($\Delta^{13}C$; $\Delta^{15}N$), TC = TOC	Texture, water holding capacity	-	-	-	-
Duong et al. 2014	[72]	Asia	Vietnam	Engineering	-	Water content, bulk density, saturated shear strength, saturated hydraulic conductivity, dry density, main grain size, effective cohesion, texture	-	-	-	-
Duró et al. 2020	[73]	Europe	Netherlands	Engineering	-	Internal friction angle, cohesion, texture, shear stress	-	-	-	-
Dybala et al. 2019	[74]	North America	USA, California	Other	TC, carbon stock	Bulk density	-	Cosumnes (Fine, mixed, active, nonacid, thermic Aquic Xerofluvents)	-	-
Fernandes et al. 2020	[75]	Europe	Portugal	Engineering	-	Cohesion	-	-	-	-
Fournier et al. 2015	[76]	Europe	Switzerland	Other	-	Hydric conditions	Species traits	-	-	-
Fournier et al. 2013	[33]	Europe	Switzerland	Other	OM, OM-type, hydromorphological features	Texture, coarse elements	Root density, biological activity features	RP (2009) (WRB 2006): REDOXISOLS fluviques carbonatés (Gleyic Fluvisols (Calcaric)); FLUVIOSOLS brut carbonatés (Regosols (Calcaric)); FLUVIOSOLS typiques carbonatés (Fluvisols (Calcaric)); FLUVIOSOLS typiques redoxiques carbonatés (Fluvisols (Calcaric) with redoximorphic features); REDUCTISOLS fluviques carbonatés (Gleysols (Calcaric))	-	Soil morphology: soil diversity, soil dynamism, soil typicality
Franklin et al. 2020	[77]	Oceania	Australia	Other	TN, TC, NH_4^+ -N, NO_3^- -N, pH, OC; (DOM, DOC, DON, C/N, TDC, TDN, inorganic N in leachate)	Texture, moisture	-	Hard pedal mottled-yellow-grey duplex soil (Atlas of Australian Soils 1960–1968); USDA (2014): Paleustalf	-	-
Gageler et al. 2014	[78]	Oceania	Australia	Management	TN, SOC, NO_3^-, NH_4^+	Texture, infiltration, bulk density	-	Red Ferrosols; Clay loamy (ASC 1996); WRB (2014): Nitisols	-	-
Garvin et al. 2017	[79]	North America	USA, Oklahoma	Other	Cd, Pb, Zn	-	-	-	-	-

Table A1. *Cont.*

Source	#Article	Continent	Country	Category	Chemical Properties	Physical Properties	Biological Properties	Detailed Classification	Other Classification	Other Soil Data
Giese et al. 2000	[80]	North America	USA, South Carolina	Other	SOC	-	-	Typic Endoaquepts; Typic Fluvaquents; Thapto-Histic Fluvaquents; Grossarenic Hapludults; Arenic Endoaquults	-	-
Gift et al. 2010	[3]	North America	USA, Maryland	Other	OM, N_2O	Moisture	DEA, root biomass	-	-	-
Gold et al. 2001	[81]	North America	USA, various	Other	hydromorphological features	Soil wetness	-	-	Hydric soils	-
Gumiero & Boz 2017	[82]	Europe	Italy	Management	Moderately calcareous	Water content, texture, drainage	-	-	-	-
Guo et al. 2018	[83]	Asia	China	Other	Organo-chlorine pesticides	Texture	Soil microbial community structure	-	Brown soil	-
Hale et al. 2018	[84]	Oceania	Australia	Management	TC, TN, C/N, plant available P, CPOM	-	-	-	-	-
Hale et al. 2014	[85]	Oceania	Australia	Management	EC, pH, inorganic N (NO_3^-, N_2O, NH_4^+), TC, TN, plant available P	Water content, bulk density, texture	-	Various soil types (ASC 1996)	-	-
Harrison et al. 2011	[86]	North America	USA, Maryland	Other	N_2O, N_2	-	-	-	-	-
Hasselquist et al. 2017	[87]	Europe	Sweden	Other	$\Delta^{15}N$, bulk C and N, C/N	Texture	-	-	-	-
Higgisson et al. 2019	[88]	Oceania	Australia	Management	-	Particle size	-	-	-	-
Jansen & Robertson 2001	[89]	Oceania	Australia	Management	-	Bank stability, soil structure	-	-	-	-
Janssen et al. 2019	[90]	Europe	France, Switzerland	Engineering	-	-	-	-	-	-
Juracek & Drake 2016	[91]	North America	USA, Kansas	Other	Pb, Zn	Particle size	-	-	-	-
Kauffman et al. 2004	[35]	North America	USA, Oregon	Management	SOM, mineral N (NO_3^--N, NH_4^+ -N)	Texture, bulk density, porosity, infiltration rates, moisture	TBGB, net potential nitrification, net potential N mineralization	Cryofluvents	-	-
Korol et al. 2019	[92]	North America	USA, various	Management	pH, OM, NO_3^-, NH_4^+, TC, TN, SRP	Bulk density, moisture	Denitrification potential, DEA, potential C mineralization	-	-	-
Langendoen et al. 2009	[93]	North America	USA, Mississippi	Engineering	-	Shear strength, pore-water pressure, cohesion, friction angle, bulk density, texture, saturated hydraulic conductivity	-	-	-	-
Larsen & Greco 2002	[94]	North America	USA, California	Engineering	-	Bank cohesion, texture	-	-	-	-
Laub et al. 2013	[25]	North America	USA, Maryland	Management	SOM	Bulk density, moisture, texture	Root biomass	Zekiah (Coarse-loamy, siliceous, active, acid, mesic Typic Fluvaquents); Issue (Coarse-loamy, mixed, active, mesic Fluvaquentic Dystrudepts); Hatboro (Fine-loamy, mixed, active, nonacid, mesic Fluvaquentic Endoaquepts); Fallsington (Fine-loamy, mixed, active, mesic Typic Endoaquults), Widewater (Fine-loamy, mixed, active, acid, mesic Fluvaquentic Endoaquepts); Codorus (Fine-loamy, mixed, active, mesic Fluvaquentic Dystrudepts); Lindside (Fine-silty, mixed, active, mesic Fluvaquentic Eutrudepts)	-	-

Table A1. *Cont.*

Source	#Article	Continent	Country	Category	Chemical Properties	Physical Properties	Biological Properties	Detailed Classification	Other Classification	Other Soil Data
Lee et al. 2011	[95]	Asia	South Korea	Other	-	-	-	-	-	Soil information (= soil properties; not further specified) from soil maps is used in model
Li et al. 2006	[96]	Asia	China	Engineering	-	Moisture, shear stress	-	-	-	-
Lindow et al. 2009	[97]	n.a.	n.a.	Engineering	-	Texture, hydraulic conductivity, van Genuchten parameters, effective cohesion, internal friction angle, residual and saturated water content	-	-	-	-
Maffra & Sutili 2020	[98]	South America	Brazil	Engineering	-	-	-	-	-	-
Maroto et al. 2017	[99]	Europe	Spain	Engineering	-	Texture	-	-	-	Poorly developed soil
Marquez et al. 2017	[100]	North America	USA, Iowa	Other	-	-	-	Coland (Fine-loamy, mixed, superactive, mesic Cumulic Endoaquoll)	-	-
Matheson et al. 2002	[101]	Oceania	New Zealand	Other	NO_3^-, NH_4^+	Bulk density, moisture content	-	NZG (1948): Waingaro steepland soil (northern yellow-brown earth); USDA (1975): Umbric Dystrochrept	-	-
Meals & Hopkins 2002	[102]	North America	USA, Vermont	Management	-	-	-	-	Alluvial and lacustrine soils	-
Meynendonckx et al. 2006	[103]	Europe	Belgium	Other	-	Drainage, texture	-	-	-	-
Neilen et al. 2017	[104]	Oceania	Australia	Other	NO_3^--N, NH_4^+-N, DON, DOC, SRP in leachate	-	-	Haplic, Mesotrophic, Red Ferrosols (ASC 2016)	-	-
Orr et al. 2007	[105]	North America	USA, Wisconsin	Other	OM, NO_3^--N	Moisture, texture	Actual denitrification potential, DEA	-	-	-
Peter et al. 2012	[106]	Europe	Switzerland	Other	-	Texture	-	-	-	-
Petrone & Preti 2010	[107]	South America	Nicaragua	Engineering	-	Texture	-	-	-	-
Pinto et al. 2016	[108]	Europe	Portugal	Engineering	-	"physical riverbank conditions" not further specified	-	-	-	-
Rahe et al. 2015	[109]	North America	USA, Illinois	Management	TC, TN, C/N, plant available P, CPOM	Infiltration, bulk density, moisture, texture, drainage	-	Swanwick (Fine-silty, spolic, mixed, active, nonacid, mesic Anthroportic Udorthents); Lenzburg (Fine-loamy, spolic, mixed, active, calcareous, mesic Anthroportic Udorthents)	-	-
Rassam & Pagendam 2009	[110]	Oceania	Australia	Management	-	Hydraulic conductivity (subsoil)	Denitrification rates	-	-	-
Recking et al. 2019	[32]	Europe	"alpine context"	Engineering	-	Cohesion, texture	-	-	-	-
Reisinger et al. 2013	[111]	North America	USA, Kansas	Other	-	-	-	Ivan (Fine-silty, mixed, superactive, mesic Cumulic Hapludolls)	-	-
Remo et al. 2017	[112]	North America	USA, Illinois	Management	-	Texture, drainage class, water retention capacity	-	Soil order (not further specified)	-	Data obtained from SSURGO
Rheinhardt et al. 2012	[113]	North America	USA, North Carolina	Other	SOM, SOC content	Bulk density	-	-	-	-
Rimondi et al. 2019	[114]	Europe	Italy	Other	Hg, As, Cd, Pb, Sb, Cr, Zn, Cu, Sn, V	-	-	-	-	-

Table A1. *Cont.*

Source	#Article	Continent	Country	Category	Chemical Properties	Physical Properties	Biological Properties	Detailed Classification	Other Classification	Other Soil Data
Rosenblatt et al. 2001	[115]	North America	USA, Rhode Island	Management	-	-	-	Inceptisols; Histosols; Entisols	-	-
Rosenfeld et al. 2011	[116]	Europe/North America	Sweden, Finland, Canada	Management	-	-	-	-	-	-
Saad et al. 2018	[117]	South America	Brazil	Management	-	Erodibility of soil classes, texture	-	SiBCS (2018): Argissolo Vermelho-Amarelo; Cambissolo Húmico; Neossolo Litólico; Neossolo Flúvico; Cambissolo Háplico USDA (2014): Ultisol; Inceptisol; Udorthent; Fluvent USDA (1996): Ochrept	-	-
Samaritani et al. 2011	[118]	Europe	Switzerland	Other	pH, TN, TOC, TIC, available P, C pools and fluxes	Texture, temperature	-	-	-	-
Sgouridis et al. 2011	[119]	Europe	UK	Other	-	Texture (topsoil)	-	Pelo-stagnogley soils; Stagnogley soils; Brown rendzinas; Gleyic brown calcareous earths; Grey rendzinas	-	-
Shah et al. 2010	[120]	North America	USA, New Mexico	Other	-	-	-	Typic Ustifluvents (Gila-Vinton-Brazito association)	-	-
Silk et al. 2006	[121]	North America	USA, California	Other	Bioavailable Cu, oxide-bound Cu, pH	-	-	-	-	-
Smith et al. 2012	[37]	Oceania	Australia	Other	NO_3^-, NO_2^-, NH_4^+, TC, TN, chemical nature of soil C	Texture, bulk density, gravimetric moisture	Potential mineralizable N, net nitrification	Red Chromosol (ASC 1996)	-	-
Sutton-Grier et al. 2009	[38]	North America	USA, North Carolina	Other	SOM, NO_3^--N, NH_4^+-N, inorganic P, C/N	Bulk density	Microbial biomass C, DEA	Monacan (Fine-loamy, mixed, active, thermic Fluvaquentic Eutrudepts)	-	-
Tang et al. 2016	[122]	Europe	Netherlands	Other	OM, plant available P, amorphous Fe, Fe-bound P, aluminum-bound P	Bulk density, texture	-	-	-	-
Tererai et al. 2015	[123]	Africa	South Africa	Other	-	-	-	-	Deep greyish alluvial soils	-
Theriot et al. 2013	[124]	North America	USA, Arkansas	Other	TC, TN, TP	Bulk density, moisture	Microbial biomass N, potential mineralizable N, potential denitrification	-	-	-
Tian et al. 2004	[125]	North America	USA, North Carolina	Management	pH, TN, TC, NO_3^-	-	Microbial biomass, denitrifier density, ammonium oxidizer density	-	-	-
Tomer et al. 2015	[126]	North America	USA, Iowa, Illinois	Management	-	-	-	Tama (Typic Argiudolls); Saude (Typic Hapludolls); Webster (Typic Endoaquolls); Osco (Mollic Hapludalfs)	Hydric soils	-
Unghire et al. 2011	[4]	North America	USA, North Carolina	Management	SOM, inorganic nutrients (NO_2^-, NO_3^-, inorganic P)	Moisture, bulk density, clay content	-	Cartecay (Coarse-loamy, mixed, semiactive, nonacid, thermic Aquic Udifluvents); Chewacla (Fine-loamy, mixed, active, thermic Fluvaquentic Dystrudepts)	-	-

Table A1. *Cont.*

Source	#Article	Continent	Country	Category	Chemical Properties	Physical Properties	Biological Properties	Detailed Classification	Other Classification	Other Soil Data
Vandecasteele et al. 2004	[127]	Europe	Belgium	Other	Cd, Cr, Zn, Cu, Ni, Pb, P, S, TN, $CaCO_3$, OC, pH	EC, texture	-	-	-	-
Walker et al. 2002	[128]	North America	USA, Georgia	Other	NO_3^-, NH_4^+, NH_3, NO, N_2O	Water content	-	Saunook (Fine-loamy, mixed, superactive, mesic Humic Hapludults)	-	-
Walker et al. 2009	[129]	North America	USA, North Carolina	Other	NO_3^-, NH_4^+, NO_2^-, TN, TC	Moisture	-	Rosman (Coarse-loamy, mixed, superactive, mesic Fluventic Humudepts)	-	-
Wang et al. 2019	[130]	Asia	China	Other	pH, SOM, TN, TP, TK, available N/P/K	Texture, water content	Soil microbial number (bacteria, actinomycete, fungi), soil enzyme activity, operational taxonomic units, phylogenetic diversity			
Wang et al. 2014	[131]	Asia	China	Other	NH_4^+-N, NO_3^--N, NO_2^--N, TN, PO_4^{3-} in water	Texture	Diversity and distribution of microbial community	-	-	-
Weller & Baker 2014	[132]	North America	USA, various	Other	NO_3^-	-	-	-	-	-
Welsh et al. 2017	[133]	North America	USA, North Carolina	Other	pH, OM, NO_3^-, NH_4^+, TC, TN, SRP	Moisture, texture	DEA	-	-	-
Welsh et al. 2019	[134]	North America	USA, North Carolina	Other	-	Texture	-	-	-	-
Xiong et al. 2015	[135]	Asia	China	Other	pH, OM, TN	Texture, moisture, bulk density	-	-	-	-
Ye et al. 2019	[136]	Asia	China	Other	Hg, As, Cr, Cd, Pb, Cu, Fe, Mn, Zn, SOM, TP, pH	Moisture, texture	-	-	-	-
Young et al. 2013	[137]	North America	USA, Vermont	Other	TP, pH, OM, different P speciations	-	-	-	-	-
Zaimes et al. 2006	[138]	North America	USA, Iowa	Management	-	Texture, bulk density, permeability	-	Spillville (Fine loamy, mixed, superactive, mesic Cumulic Hapludolls); Coland (Fine-loamy, mixed, mesic, superactive Cumulic Endoaquolls)	-	-
Zhang et al. 2018	[39]	Asia	China	Engineering	-	Texture, shear strength	Root system, root biomass	-	-	-
Zhao et al. 2013	[139]	Asia	China	Management	-	Erodibility	-	-	-	Soil map (1: 1,000,000); China soil scientific database (soil properties not further specified)

References

1. Christiansen, T.; Azlak, M.; Ivits-Wasser, E. *Floodplains: A Natural System to Preserve and Restore*; EEA Report 24/2019; European Environment Agency: Luxembourg, 2020.
2. Malmqvist, B.; Rundle, S. Threats to the running water ecosystems of the world. *Environ. Conserv.* **2002**, *29*, 134–153. [CrossRef]
3. Gift, D.M.; Groffman, P.M.; Kaushal, S.S.; Mayer, P.M. Denitrification Potential, Root Biomass, and Organic Matter in Degraded and Restored Urban Riparian Zones. *Restor. Ecol.* **2010**, *18*, 113–120. [CrossRef]
4. Unghire, J.M.; Sutton-Grier, A.E.; Flanagan, N.E.; Richardson, C.J. Spatial Impacts of Stream and Wetland Restoration on Riparian Soil Properties in the North Carolina Piedmont. *Restor. Ecol.* **2010**, *19*, 738–746. [CrossRef]
5. Junk, W.J.; Welcomme, R. Floodplains. In *Wetlands and Shallow Continental Water Bodies*; Patten, B.C., Ed.; SPB Academic Publishers: The Hague, The Netherlands, 1990; Volume 1, pp. 491–524. ISBN 905-103-146-0.
6. Thoms, M. Floodplain–river ecosystems: Lateral connections and the implications of human interference. *Geomorphology* **2003**, *56*, 335–349. [CrossRef]
7. Nilsson, C.; Berggren, K. Alterations of Riparian Ecosystems Caused by River Regulation: Dam operations have caused global-scale ecological changes in riparian ecosystems. How to protect river environments and human needs of rivers remains one of the most important questions of our time. *Bioscience* **2000**, *50*, 783–792. [CrossRef]
8. Naiman, R.J.; Bilby, R.E.; Bisson, P.A. Riparian Ecology and Management in the Pacific Coastal Rain Forest. *Bioscience* **2000**, *50*, 996–1011. [CrossRef]
9. Burger, B.; Reich, P.; Cavagnaro, T.R. Trajectories of change: Riparian vegetation and soil conditions following livestock removal and replanting. *Austral. Ecol.* **2010**, *35*, 980–987. [CrossRef]
10. Tockner, K.; Stanford, J.A. Riverine flood plains: Present state and future trends. *Environ. Conserv.* **2002**, *29*, 308–330. [CrossRef]
11. Palmer, M.A.; Ruhi, A. Linkages between flow regime, biota, and ecosystem processes: Implications for river restoration. *Science* **2019**, *365*, eaaw2087. [CrossRef]
12. Vanneuville, W.; Wolters, H.; Scholz, M.; Werner, B.; Uhel, R. *Flood Risks and Environmental Vulnerability—Exploring the Synergies between Floodplain Restoration, Water Policies and Thematic Policies*; EEA Report 1/2016; European Environment Agency: Luxembourg, 2016.
13. Boettinger, J.L. Alluvium and alluvial soils. In *Encyclopedia of Soils in the Environment*; Hillel, D., Ed.; Elsevier: Oxford, UK, 2005; pp. 45–49. [CrossRef]
14. Gerrard, J. *Alluvial Soils*; Van Nostrand Reinhold Co.: New York, NY, USA, 1987; ISBN 044-222-742-6.
15. IUSS Working Group WRB. *World Reference Base for Soil Resources 2014, Update 2015. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*; World Soil Resources Reports 106; FAO: Rome, Italy, 2015.
16. Soil Survey Staff. *Keys to Soil Taxonomy*, 12th ed.; United States Department of Agriculture—Natural Resources Conservation Service: Washington, DC, USA, 2014.
17. Daniels, J. Floodplain aggradation and pedogenesis in a semiarid environment. *Geomorphology* **2003**, *56*, 225–242. [CrossRef]
18. Bullinger-Weber, G.; Gobat, J.-M. Identification of facies models in alluvial soil formation: The case of a Swiss alpine floodplain. *Geomorphology* **2006**, *74*, 181–195. [CrossRef]
19. Palmer, M.; Bernhardt, E.; Allan, J.D.; Lake, P.; Alexander, G.; Brooks, S.; Carr, J.; Clayton, S.; Dahm, C.N.; Follstad Shah, J.; et al. Standards for ecologically successful river restoration. *J. Appl. Ecol.* **2005**, *42*, 208–217. [CrossRef]
20. Roni, P.; Hanson, K.; Beechie, T. Global Review of the Physical and Biological Effectiveness of Stream Habitat Rehabilitation Techniques. *N. Am. J. Fish. Manag.* **2008**, *28*, 856–890. [CrossRef]
21. Hornung, L.K.; Podschun, S.A.; Pusch, M. Linking ecosystem services and measures in river and floodplain management. *Ecosyst. People* **2019**, *15*, 214–231. [CrossRef]
22. European Centre for River Restoration. Regional and National Policies. Available online: https://www.ecrr.org/River-Restoration/Regional-and-national-policies (accessed on 4 December 2020).
23. Bruland, G.L.; Richardson, C.J. Spatial Variability of Soil Properties in Created, Restored, and Paired Natural Wetlands. *Soil Sci. Soc. Am. J.* **2005**, *69*, 273–284. [CrossRef]
24. Jähnig, S.C.; Brabec, K.; Buffagni, A.; Erba, S.; Lorenz, A.W.; Ofenböck, T.; Verdonschot, P.F.M.; Hering, D. A comparative analysis of restoration measures and their effects on hydromorphology and benthic invertebrates in 26 central and southern European rivers. *J. Appl. Ecol.* **2010**, *47*, 671–680. [CrossRef]
25. Laub, B.G.; McDonough, O.T.; Needelman, B.A.; Palmer, M.A. Comparison of Designed Channel Restoration and Riparian Buffer Restoration Effects on Riparian Soils. *Restor. Ecol.* **2013**, *21*, 695–703. [CrossRef]
26. Ballantine, K.; Schneider, R. Fifty-five years of soil development in restored freshwater depressional wetlands. *Ecol. Appl.* **2009**, *19*, 1467–1480. [CrossRef]
27. Cole, C.A.; Kentula, M.E. Monitoring and Assessment—What to Measure . . . and Why. In *Wetlands: Integrating Multidisciplinary Concepts*; LePage, B.A., Ed.; Springer: Dordrecht, The Netherlands, 2011; pp. 137–152. ISBN 978-94-007-0551-7.
28. Dietrich, A.L.; Lind, L.; Nilsson, C.; Jansson, R. The Use of Phytometers for Evaluating Restoration Effects on Riparian Soil Fertility. *J. Environ. Qual.* **2014**, *43*, 1916–1925. [CrossRef]

29. Haines-Young, R.; Potschin, M.B. *Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure*; CICES: Sale, UK, 2018.
30. Pickering, C.; Byrne, J. The benefits of publishing systematic quantitative literature reviews for PhD candidates and other early-career researchers. *High. Educ. Res. Dev.* **2014**, *33*, 534–548. [CrossRef]
31. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med.* **2009**, *6*, e1000097. [CrossRef] [PubMed]
32. Recking, A.; Piton, G.; Montabonnet, L.; Posi, S.; Evette, A. Design of fascines for riverbank protection in alpine rivers: Insight from flume experiments. *Ecol. Eng.* **2019**, *138*, 323–333. [CrossRef]
33. Schultz, J. *The Ecozones of the World*, 2nd ed.; Springer: Berlin/Heidelberg, Germany, 2005; ISBN 978-2-540-28527-4.
34. Fournier, B.; Guenat, C.; Bullingerweber, G.; Mitchell, E.A.D. Spatio-temporal heterogeneity of riparian soil morphology in a restored floodplain. *Hydrol. Earth Syst. Sci.* **2013**, *17*, 4031–4042. [CrossRef]
35. Kauffman, J.B.; Thorpe, A.S.; Brookshire, E.N.J. Livestock exclusion and belowground ecosystem responses in riparian meadows of Eastern Oregon. *Ecol. Appl.* **2004**, *14*, 1671–1679. [CrossRef]
36. Clement, J.C.; Holmes, R.M.; Peterson, B.J.; Pinay, G. Isotopic investigation of denitrification in a riparian ecosystem in western France. *J. Appl. Ecol.* **2003**, *40*, 1035–1048. [CrossRef]
37. Smith, M.; Conte, P.; Berns, A.E.; Thomson, J.R.; Cavagnaro, T.R. Spatial patterns of, and environmental controls on, soil properties at a riparian–paddock interface. *Soil Biol. Biochem.* **2012**, *49*, 38–45. [CrossRef]
38. Sutton-Grier, A.E.; Ho, M.; Richardson, C.J. Organic amendments improve soil conditions and denitrification in a restored riparian wetland. *Wetlands* **2009**, *29*, 343–352. [CrossRef]
39. Zhang, D.; Cheng, J.; Liu, Y.; Zhang, H.; Ma, L.; Mei, X.; Sun, Y. Spatio-Temporal Dynamic Architecture of Living Brush Mattress: Root System and Soil Shear Strength in Riverbanks. *Forests* **2018**, *9*, 493. [CrossRef]
40. Kuykendall, H. *Soil Quality Physical Indicators: Selecting Dynamic Soil Properties to Assess Soil Function*; Soil Quality Technical Note No. 10; United States Department of Agriculture—Natural Resources Conservation Service: Washington, DC, USA, 2008.
41. Karlen, D.L.; Mausbach, M.J.; Doran, J.W.; Cline, R.G.; Harris, R.F.; Schuman, G.E. Soil Quality: A Concept, Definition, and Framework for Evaluation (A Guest Editorial). *Soil Sci. Soc. Am. J.* **1997**, *61*, 4–10. [CrossRef]
42. National Soil Survey Center. *Soil Quality Information Sheet. Indicators for Soils Quality Evaluation*; United States Department of Agriculture—Natural Resources Conservation Service: Washington, DC, USA, 1996.
43. Häusler, S.; Salm, C. *Bodenschutz beim Bauen (Soil Protection and Construction)*; Leitfaden Umwelt Nummer 10; BUWAL Bundesamt für Umwelt, Wald und Landschaft: Bern, Switzerland, 2001.
44. Soil Geographic Databases. Available online: https://www.isric.org/index.php/explore/soil-geographic-databases (accessed on 4 December 2020).
45. WoSIS Soil Profile Database. Available online: https://www.isric.org/index.php/explore/wosis (accessed on 4 December 2020).
46. New Edition of Soil Property Estimates for the World with Associated Web Platform Released (SoilGrids250m). Available online: https://www.isric.org/news/new-edition-soil-property-estimates-world-associated-web-platform-released-soilgrids250m (accessed on 4 December 2020).
47. Bellini, E. *Boden und Bauen. Stand der Technik und Praktiken (Soil and Construction. State of the Knowledge)*; Umwelt-Wissen Nr. 1508; BAFU Bundesamt für Umwelt: Bern, Switzerland, 2015.
48. Bundesverband Boden. *Bodenkundliche Baubegleitung BBB (Soil Protection on Construction Sites). Leitfaden für die Praxis. BVB-Merkblatt. Band 2*; Erich Schmidt Verlag: Berlin, Germany, 2013.
49. Fisher, J.; Cortina-Segarra, J.; Grace, M.; Moreno-Mateos, D.; Rodíguez Gonzáles, P.; Baker, S.; Frouz, J.; Klimkowska, A.; Andres, P.; Kyriazopoulos, A.; et al. *What Is Hampering Current Restoration Effectiveness? An EKLIPSE Expert Working Group Report*; UK Centre for Ecology & Hydrology: Wallingford, UK, 2019.
50. United States Department of Agriculture; Natural Resources Conservation Service. Site Assessment and Investigation. In *Stream Restoration Design National Engineering Handbook (Part 654)*; USDA, NRCS, Eds.; United States Department of Agriculture—Natural Resources Conservation Service: Washington, DC, USA, 2007.
51. Rey, F.; Bifulco, C.; Bischetti, G.B.; Bourrier, F.; De Cesare, G.; Florineth, F.; Graf, F.; Marden, M.; Mickovski, S.B.; Phillips, C.J.; et al. Soil and water bioengineering: Practice and research needs for reconciling natural hazard control and ecological restoration. *Sci. Total Environ.* **2019**, *648*, 1210–1218. [CrossRef]
52. Agouridis, C.T.; Edwards, D.R.; Workman, S.R.; Bicudo, J.R.; Koostra, B.K.; VanZant, E.S.; Taraba, J.L. Streambank erosion associated with grazing practices in the humid region. *Trans. ASAE* **2005**, *48*, 181–190. [CrossRef]
53. Amézketa, E.; del Valle de Lersundi, J. Soil classification and salinity mapping for determining restoration potential of cropped riparian areas. *Land Degrad. Dev.* **2008**, *19*, 153–164. [CrossRef]
54. Andrews, D.M.; Barton, C.D.; Kolka, R.K.; Rhoades, C.C.; Dattilo, A.J. Soil and Water Characteristics in Restored Canebrake and Forest Riparian Zones1. *JAWRA J. Am. Water Resour. Assoc.* **2011**, *47*, 772–784. [CrossRef]
55. Anstead, L.; Boar, R.R.; Tovey, N.K. The effectiveness of a soil bioengineering solution for river bank stabilisation during flood and drought conditions: Two case studies from East Anglia. *Area* **2012**, *44*, 479–488. [CrossRef]
56. Asghari, H.R.; Cavagnaro, T.R. Arbuscular mycorrhizas enhance plant interception of leached nutrients. *Funct. Plant Biol.* **2011**, *38*, 219–226. [CrossRef] [PubMed]

57. Atkinson, S.F.; Lake, M.C. Prioritizing riparian corridors for ecosystem restoration in urbanizing watersheds. *PeerJ* **2020**, *8*, e8174. [CrossRef]
58. Bariteau, L.; Bouchard, D.; Gagnon, G.; Levasseur, M.; Lapointe, S.; Bérubé, M. A riverbank erosion control method with environmental value. *Ecol. Eng.* **2013**, *58*, 384–392. [CrossRef]
59. Beauchamp, V.B.; Swan, C.M.; Szlavecz, K.; Hu, J. Riparian community structure and soil properties of restored urban streams. *Ecohydrology* **2015**, *8*, 880–895. [CrossRef]
60. Bedison, J.E.; Scatena, F.N.; Mead, J.V. Influences on the spatial pattern of soil carbon and nitrogen in forested and non-forested riparian zones in the Atlantic Coastal Plain of the Delaware River Basin. *For. Ecol. Manag.* **2013**, *302*, 200–209. [CrossRef]
61. Bissels, S.; Hölzel, N.; Donath, T.W.; Otte, A. Evaluation of restoration success in alluvial grasslands under contrasting flooding regimes. *Biol. Conserv.* **2004**, *118*, 641–650. [CrossRef]
62. Botero-Acosta, A.; Chu, M.L.; Guzman, J.A.; Starks, P.J.; Moriasi, D.N. Riparian erosion vulnerability model based on environmental features. *J. Environ. Manag.* **2017**, *203*, 592–602. [CrossRef] [PubMed]
63. Brovelli, A.; Batlle-Aguilar, J.; Barry, D.A. Analysis of carbon and nitrogen dynamics in riparian soils: Model development. *Sci. Total. Environ.* **2012**, *429*, 231–245. [CrossRef] [PubMed]
64. Buchanan, B.P.; Walter, M.T.; Nagle, G.N.; Schneider, R.L. Monitoring and assessment of a river restoration project in central New York. *River Res. Appl.* **2010**, *28*, 216–233. [CrossRef]
65. Buzhdygan, O.Y.; Rudenko, S.S.; Kazanci, C.; Patten, B.C. Effect of invasive black locust (Robinia pseudoacacia L.) on nitrogen cycle in floodplain ecosystem. *Ecol. Model.* **2016**, *319*, 170–177. [CrossRef]
66. Cabezas, Á.; Comín, F.A. Carbon and nitrogen accretion in the topsoil of the Middle Ebro River Floodplains (NE Spain): Implications for their ecological restoration. *Ecol. Eng.* **2010**, *36*, 640–652. [CrossRef]
67. Das, U.K. A Case Study on Performance of Jia Bharali River Bank Protection Measure Using Geotextile Bags. *Int. J. Geosynth. Ground Eng.* **2016**, *2*, 2. [CrossRef]
68. Davis, C.A.; Austin, J.E.; Buhl, D.A. Factors influencing soil invertebrate communities in riparian grasslands of the central platte river floodplain. *Wetlands* **2006**, *26*, 438–454. [CrossRef]
69. De Mello, K.; Randhir, T.O.; Valente, R.A.; Vettorazzi, C.A. Riparian restoration for protecting water quality in tropical agricultural watersheds. *Ecol. Eng.* **2017**, *108*, 514–524. [CrossRef]
70. Del Tánago, M.G.; De Jalón, D.G. Attributes for assessing the environmental quality of riparian zones. *Limnetica* **2006**, *25*, 389–402.
71. Dhondt, K.; Boeckx, P.; Verhoest, N.E.C.; Hofman, G.; Van Cleemput, O. Assessment of Temporal and Spatial Variation of Nitrate Removal in Riparian Zones. *Environ. Monit. Assess.* **2006**, *116*, 197–215. [CrossRef]
72. Duong, T.T.; Komine, H.; Do, M.D.; Murakami, S. Riverbank stability assessment under flooding conditions in the Red River of Hanoi, Vietnam. *Comput. Geotech.* **2014**, *61*, 178–189. [CrossRef]
73. Duró, G.; Crosato, A.; Kleinhans, M.G.; Winkels, T.G.; Woolderink, H.A.G.; Uijttewaal, W.S.J. Distinct patterns of bank erosion in a navigable regulated river. *Earth Surf. Process. Landf.* **2019**, *45*, 361–374. [CrossRef]
74. Dybala, K.E.; Steger, K.; Walsh, R.G.; Smart, D.R.; Gardali, T.; Seavy, N.E. Optimizing carbon storage and biodiversity co-benefits in reforested riparian zones. *J. Appl. Ecol.* **2019**, *56*, 343–353. [CrossRef]
75. Fernandes, L.F.S.; Pinto, A.A.; Terêncio, D.P.; Pacheco, F.A.L.; Cortes, R.M. Combination of Ecological Engineering Procedures Applied to Morphological Stabilization of Estuarine Banks after Dredging. *Water* **2020**, *12*, 391. [CrossRef]
76. Fournier, B.; Gillet, F.; Le Bayon, R.-C.; Mitchell, E.A.D.; Moretti, M. Functional responses of multitaxa communities to disturbance and stress gradients in a restored floodplain. *J. Appl. Ecol.* **2015**, *52*, 1364–1373. [CrossRef]
77. Franklin, H.M.; Carroll, A.R.; Chen, C.; Maxwell, P.; Burford, M.A. Plant source and soil interact to determine characteristics of dissolved organic matter leached into waterways from riparian leaf litter. *Sci. Total Environ.* **2020**, *703*, 134530. [CrossRef]
78. Gageler, R.; Bonner, M.; Kirchhof, G.; Amos, M.; Robinson, N.; Schmidt, S.; Shoo, L.P. Early Response of Soil Properties and Function to Riparian Rainforest Restoration. *PLoS ONE* **2014**, *9*, e104198. [CrossRef]
79. Garvin, E.M.; Bridge, C.F.; Garvin, M.S. Screening Level Assessment of Metal Concentrations in Streambed Sediments and Floodplain Soils within the Grand Lake Watershed in Northeastern Oklahoma, USA. *Arch. Environ. Contam. Toxicol.* **2017**, *72*, 349–363. [CrossRef]
80. Giese, L.A.; Aust, W.M.; Trettin, C.C.; Kolka, R.K. Spatial and temporal patterns of carbon storage and species richness in three South Carolina coastal plain riparian forests. *Ecol. Eng.* **2000**, *15*, S157–S170. [CrossRef]
81. Gold, A.J.; Groffman, P.M.; Addy, K.; Kellogg, D.Q.; Stolt, M.; Rosenblatt, A.E. Landscape attributes as controls on groithd water nitrate removal capacity of riparian zones. *JAWRA J. Am. Water Resour. Assoc.* **2001**, *37*, 1457–1464. [CrossRef]
82. Gumiero, B.; Boz, B. How to stop nitrogen leaking from a Cross compliant buffer strip? *Ecol. Eng.* **2017**, *103*, 446–454. [CrossRef]
83. Guo, F.; Sun, L.; Hu, X.; Luo, Q. Correlation analysis of OCPs (organo-chlorine pesticides) and microbial community diversity in the riparian zone of Liaohe River Conservation Area. *Fresenius Environ. Bull.* **2018**, *27*, 6844–6852.
84. Hale, R.; Reich, P.; Daniel, T.; Lake, P.S.; Cavagnaro, T.R. Assessing changes in structural vegetation and soil properties following riparian restoration. *Agric. Ecosyst. Environ.* **2018**, *252*, 22–29. [CrossRef]
85. Hale, R.; Reich, P.; Daniel, T.; Lake, P.S.; Cavagnaro, T.R. Scales that matter: Guiding effective monitoring of soil properties in restored riparian zones. *Geoderma* **2014**, *228*, 173–181. [CrossRef]
86. Harrison, M.D.; Groffman, P.M.; Mayer, P.M.; Kaushal, S.S.; Newcomer, T.A. Denitrification in Alluvial Wetlands in an Urban Landscape. *J. Environ. Qual.* **2011**, *40*, 634–646. [CrossRef]

87. Hasselquist, E.M.; Hasselquist, N.J.; Sparks, J.P.; Nilsson, C. Recovery of nitrogen cycling in riparian zones after stream restoration using δ 15N along a 25-year chronosequence in northern Sweden. *Plant Soil* **2017**, *410*, 423–436. [CrossRef]
88. Higgisson, W.P.; Downey, P.O.; Dyer, F.J. Changes in Vegetation and Geomorphological Condition 10 Years after Riparian Restoration. *Water* **2019**, *11*, 1252. [CrossRef]
89. Jansen, A.; Robertson, A.I. Relationships between livestock management and the ecological condition of riparian habitats along an Australian floodplain river. *J. Appl. Ecol.* **2001**, *38*, 63–75.
90. Janssen, P.; Cavaillé, P.; Bray, F.; Evette, A. Soil bioengineering techniques enhance riparian habitat quality and multi-taxonomic diversity in the foothills of the Alps and Jura Mountains. *Ecol. Eng.* **2019**, *133*, 1–9. [CrossRef]
91. Juracek, K.E.; Drake, K.D. Mining-Related Sediment and Soil Contamination in a Large Superfund Site: Characterization, Habitat Implications, and Remediation. *Environ. Manag.* **2016**, *58*, 721–740. [CrossRef]
92. Korol, A.R.; Noe, G.B.; Ahn, C. Controls of the spatial variability of denitrification potential in nontidal floodplains of the Chesapeake Bay watershed, USA. *Geoderma* **2019**, *338*, 14–29. [CrossRef]
93. Langendoen, E.J.; Lowrance, R.R.; Simon, A. Assessing the impact of riparian processes on streambank stability. *Ecohydrology* **2009**, *2*, 360–369. [CrossRef]
94. Larsen, E.W.; Greco, S.E. Modeling Channel Management Impacts on River Migration: A Case Study of Woodson Bridge State Recreation Area, Sacramento River, California, USA. *Environ. Manag.* **2002**, *30*, 209–224. [CrossRef] [PubMed]
95. Lee, E.-J.; Choi, K.-S.; Kim, T.-G. Estimation of the Pollutant Removal Efficiency in a Buffer Strip Using a SWAT Model. *Environ. Eng. Res.* **2011**, *16*, 61–67. [CrossRef]
96. Li, X.; Zhang, L.; Zhang, Z. Soil bioengineering and the ecological restoration of riverbanks at the Airport Town, Shanghai, China. *Ecol. Eng.* **2006**, *26*, 304–314. [CrossRef]
97. Lindow, N.; Fox, G.A.; Evans, R.O. Seepage erosion in layered stream bank material. *Earth Surf. Process. Landf.* **2009**, *34*, 1693–1701. [CrossRef]
98. Maffra, C.; Sutili, F. The use of soil bioengineering to overcome erosion problems in a pipeline river crossing in South America. *Innov. Infrastruct. Solut.* **2020**, *5*, 1–8. [CrossRef]
99. Maroto, R.; Robredo, J.C.; García, J.L.; Giménez, M.; Tardío, G. Eresma river slope: Stabilization and restoration project (Coca, Segovia, Spain). *Procedia Environ. Sci. Eng. Manag.* **2017**, *4*, 245–254.
100. Márquez, C.O.; García, V.J.; Schultz, R.C.; Isenhart, T.M. Assessment of Soil Aggradation through Soil Aggregation and Particulate Organic Matter by Riparian Switchgrass Buffers. *Agronomy* **2017**, *7*, 76. [CrossRef]
101. Matheson, F.E.; Nguyen, M.L.; Cooper, A.B.; Burt, T.P.; Bull, D.C. Fate of 15N-nitrate in unplanted, planted and harvested riparian wetland soil microcosms. *Ecol. Eng.* **2002**, *19*, 249–264. [CrossRef]
102. Meals, D.; Hopkins, R. Phosphorus reductions following riparian restoration in two agricultural watersheds in Vermont, USA. *Water Sci. Technol.* **2002**, *45*, 51–60. [CrossRef] [PubMed]
103. Meynendonckx, J.; Heuvelmans, G.; Muys, B.; Feyen, J. Effects of watershed and riparian zone characteristics on nutrient concentrations in the River Scheldt Basin. *Hydrol. Earth Syst. Sci.* **2006**, *10*, 913–922. [CrossRef]
104. Neilen, A.D.; Chen, C.R.; Parker, B.M.; Faggotter, S.J.; Burford, M.A. Differences in nitrate and phosphorus export between wooded and grassed riparian zones from farmland to receiving waterways under varying rainfall conditions. *Sci. Total. Environ.* **2017**, *598*, 188–197. [CrossRef] [PubMed]
105. Orr, C.H.; Stanley, E.H.; Wilson, K.A.; Finlay, J.C. Effects of restoration and reflooding on soil denitrification in a leveed midwestern floodplain. *Ecol. Appl.* **2007**, *17*, 2365–2376. [CrossRef] [PubMed]
106. Peter, S.; Rechsteiner, R.; Lehmann, M.F.; Brankatschk, R.; Vogt, T.; Diem, S.; Wehrli, B.; Tockner, K.; Durisch-Kaiser, E. Nitrate removal in a restored riparian groundwater system: Functioning and importance of individual riparian zones. *Biogeosciences* **2012**, *9*, 4295–4307. [CrossRef]
107. Petrone, A.; Preti, F. Soil bioengineering for risk mitigation and environmental restoration in a humid tropical area. *Hydrol. Earth Syst. Sci.* **2010**, *14*, 239–250. [CrossRef]
108. Pinto, A.; Fernandes, L.F.S.; Maia, R. Monitoring Methodology of Interventions for Riverbanks Stabilization: Assessment of Technical Solutions Performance. *Water Resour. Manag.* **2016**, *30*, 5281–5298. [CrossRef]
109. Rahe, N.H.; Williard, K.W.; Schoonover, J.E. Restoration of Riparian Buffer Function in Reclaimed Surface Mine Soils. *JAWRA J. Am. Water Resour. Assoc.* **2015**, *51*, 898–909. [CrossRef]
110. Rassam, D.W.; Pagendam, D. Development and application of the Riparian Mapping Tool to identify priority rehabilitation areas for nitrogen removal in the Tully-Murray basin, Queensland, Australia. *Mar. Freshw. Res.* **2009**, *60*, 1165–1175. [CrossRef]
111. Reisinger, A.J.; Blair, J.M.; Rice, C.W.; Dodds, W.K. Woody Vegetation Removal Stimulates Riparian and Benthic Denitrification in Tallgrass Prairie. *Ecosystems* **2013**, *16*, 547–560. [CrossRef]
112. Remo, J.W.F.; Guida, R.J.; Secchi, S. Screening the Suitability of Levee Protected Areas for Strategic Floodplain Reconnection Along the LaGrange Segment of the Illinois River, USA. *River Res. Appl.* **2016**, *33*, 863–878. [CrossRef]
113. Rheinhardt, R.D.; Brinson, M.; Meyer, G.; Miller, K. Integrating forest biomass and distance from channel to develop an indicator of riparian condition. *Ecol. Indic.* **2012**, *23*, 46–55. [CrossRef]
114. Rimondi, V.; Costagliola, P.; Lattanzi, P.; Morelli, G.; Cara, G.; Cencetti, C.; Fagotti, C.; Fredduzzi, A.; Marchetti, G.; Sconocchia, A.; et al. A 200 km-long mercury contamination of the Paglia and Tiber floodplain: Monitoring results and implications for environmental management. *Environ. Pollut.* **2019**, *255*, 113191. [CrossRef]

115. Rosenblatt, A.E.; Gold, A.J.; Stolt, M.H.; Groffman, P.M.; Kellogg, D.Q. Identifying Riparian Sinks for Watershed Nitrate using Soil Surveys. *J. Environ. Qual.* **2001**, *30*, 1596–1604. [CrossRef] [PubMed]
116. Rosenfeld, J.S.; Hogan, D.; Palm, D.; Lundquist, H.; Nilsson, C.; Beechie, T.J. Contrasting Landscape Influences on Sediment Supply and Stream Restoration Priorities in Northern Fennoscandia (Sweden and Finland) and Coastal British Columbia. *Environ. Manag.* **2010**, *47*, 28–39. [CrossRef]
117. Saad, S.I.; Da Silva, J.M.; Silva, M.L.N.; Guimarães, J.L.B.; Júnior, W.C.S.; Figueiredo, R.D.O.; Da Rocha, H.R. Analyzing ecological restoration strategies for water and soil conservation. *PLoS ONE* **2018**, *13*, e0192325. [CrossRef]
118. Samaritani, E.; Shrestha, J.N.B.; Fournier, B.; Frossard, E.; Gillet, F.; Guenat, C.; Niklaus, P.A.; Pasquale, N.; Tockner, K.; Mitchell, E.A.D.; et al. Heterogeneity of soil carbon pools and fluxes in a channelized and a restored floodplain section (Thur River, Switzerland). *Hydrol. Earth Syst. Sci.* **2011**, *15*, 1757–1769. [CrossRef]
119. Sgouridis, F.; Heppell, C.M.; Wharton, G.; Lansdown, K.; Trimmer, M. Denitrification and dissimilatory nitrate reduction to ammonium (DNRA) in a temperate re-connected floodplain. *Water Res.* **2011**, *45*, 4909–4922. [CrossRef]
120. Shah, J.J.F.; Harner, M.J.; Tibbets, T.M. Elaeagnus angustifolia Elevates Soil Inorganic Nitrogen Pools in Riparian Ecosystems. *Ecosystems* **2010**, *13*, 46–61. [CrossRef]
121. Silk, W.K.; Bambic, D.G.; O'Dell, R.E.; Green, P.G. Seasonal and spatial patterns of metals at a restored copper mine site II. Copper in riparian soils and Bromus carinatus shoots. *Environ. Pollut.* **2006**, *144*, 783–789. [CrossRef]
122. Tang, Y.; Van Kempen, M.M.; Van Der Heide, T.; Manschot, J.J.; Roelofs, J.G.; Lamers, L.P.M.; Smolders, A.J.P. A tool for easily predicting short-term phosphorus mobilization from flooded soils. *Ecol. Eng.* **2016**, *94*, 1–6. [CrossRef]
123. Tererai, F.; Gaertner, M.; Jacobs, S.M.; Richardson, D.M. Eucalyptus Camaldulensis Invasion in Riparian Zones Reveals Few Significant Effects on Soil Physico-Chemical Properties. *River Res. Appl.* **2015**, *31*, 590–601. [CrossRef]
124. Theriot, J.M.; Conkle, J.L.; Pezeshki, S.R.; Delaune, R.D.; White, J.R. Will hydrologic restoration of Mississippi River riparian wetlands improve their critical biogeochemical functions? *Ecol. Eng.* **2013**, *60*, 192–198. [CrossRef]
125. Tian, G.L.; Vose, J.M.; Coleman, D.C.; Geron, C.D.; Walker, J.T. Evaluation of the effectiveness of riparian zone restoration in the southern Appalachians by assessing soil microbial populations. *Appl. Soil Ecol.* **2004**, *26*, 63–68. [CrossRef]
126. Tomer, M.D.; Boomer, K.M.B.; Porter, S.A.; Gelder, B.K.; James, D.E.; McLellan, E. Agricultural Conservation Planning Framework: 2. Classification of Riparian Buffer Design Types with Application to Assess and Map Stream Corridors. *J. Environ. Qual.* **2015**, *44*, 768–779. [CrossRef] [PubMed]
127. Vandecasteele, B.; Quataert, P.; De Vos, B.; Tack, F.M.G. Assessment of the pollution status of alluvial plains: A case study for the dredged sediment-derived soils along the Leie River. *Arch. Environ. Contam. Toxicol.* **2004**, *47*, 14–22. [CrossRef]
128. Walker, J.; Geron, C.D.; Vose, J.M.; Swank, W.T. Nitrogen trace gas emissions from a riparian ecosystem in southern Appalachia. *Chemosphere* **2002**, *49*, 1389–1398. [CrossRef]
129. Walker, J.; Vose, J.M.; Knoepp, J.; Geron, C.D. Recovery of Nitrogen Pools and Processes in Degraded Riparian Zones in the Southern Appalachians. *J. Environ. Qual.* **2009**, *38*, 1391–1399. [CrossRef] [PubMed]
130. Wang, J.; Wang, D.M.; Wang, B. Effects of hydrological environmental gradient on soil and microbial properties in Lijiang riparian zones of China. *Fresenius Environ. Bull.* **2019**, *28*, 1297–1307.
131. Wang, Z.; Wang, Z.; Pei, Y. Nitrogen removal and microbial communities in a three-stage system simulating a riparian environment. *Bioprocess Biosyst. Eng.* **2013**, *37*, 1105–1114. [CrossRef]
132. Weller, D.E.; Baker, M.E. Cropland Riparian Buffers throughout Chesapeake Bay Watershed: Spatial Patterns and Effects on Nitrate Loads Delivered to Streams. *JAWRA J. Am. Water Resour. Assoc.* **2014**, *50*, 696–712. [CrossRef]
133. Welsh, M.K.; McMillan, S.K.; Vidon, P.G. Denitrification along the Stream-Riparian Continuum in Restored and Unrestored Agricultural Streams. *J. Environ. Manag.* **2017**, *46*, 1010–1019. [CrossRef] [PubMed]
134. Welsh, M.K.; Vidon, P.G.; McMillan, S.K. Changes in riparian hydrology and biogeochemistry following storm events at a restored agricultural stream. *Environ. Sci. Process. Impacts* **2019**, *21*, 677–691. [CrossRef] [PubMed]
135. Xiong, Z.; Li, S.; Yao, L.; Liu, G.; Zhang, Q.; Liu, W. Topography and land use effects on spatial variability of soil denitrification and related soil properties in riparian wetlands. *Ecol. Eng.* **2015**, *83*, 437–443. [CrossRef]
136. Ye, C.; Butler, O.M.; Du, M.; Liu, W.Z.; Zhang, Q.F. Spatio-temporal dynamics, drivers and potential sources of heavy metal pollution in riparian soils along a 600 kilometre stream gradient in Central China. *Sci. Total. Environ.* **2019**, *651*, 1935–1945. [CrossRef]
137. Young, E.O.; Ross, D.S.; Cade-Menun, B.J.; Liu, C.W. Phosphorus Speciation in Riparian Soils: A Phosphorus-31 Nuclear Magnetic Resonance Spectroscopy and Enzyme Hydrolysis Study. *Soil Sci. Soc. Am. J.* **2013**, *77*, 1636–1647. [CrossRef]
138. Zaimes, G.N.; Schultz, R.C.; Isenhart, T.M. Riparian land uses and precipitation influences on stream bank erosion in central Iowa. *JAWRA J. Am. Water Resour. Assoc.* **2006**, *42*, 83–97. [CrossRef]
139. Zhao, P.; Xia, B.; Hu, Y.; Yang, Y. A spatial multi-criteria planning scheme for evaluating riparian buffer restoration priorities. *Ecol. Eng.* **2013**, *54*, 155–164. [CrossRef]