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Final knowledge assessment reports of the 3 case studies and lessons learned
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Annex C.1 -

(cf. Chapter 6.3.1)

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ENVIRONMENTAL EVIDENCE

SYSTEMATIC REVIEW PROTOCOL Open Access

Floodplain management in temperate regions: is multifunctionality enhancing biodiversity?

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Abstract

Background: Floodplains are among the most diverse, dynamic, productive and populated but also the most threatened ecosystems on Earth. Threats are mainly related to human activities that alter the landscape and disrupt fluvial processes to obtain benefits related to multiple ecosystem services (ESS). Floodplain management therefore requires close coordination among interest groups with competing claims and poses multi-dimensional challenges to policy-makers and project managers. The European Commission proposed in its recent Biodiversity Strategy to maintain and enhance European ecosystems and their services by establishing green infrastructure (GI). GI is assumed to provide multiple ecosystem functions and services including the conservation of biodiversity in the same spatial area. However, evidence for biodiversity benefits of multifunctional floodplain management is scattered and has not been synthesised.

Methods/design: This protocol specifies the methods for conducting a systematic review to answer the following policy-relevant questions: a) what is the impact of floodplain management measures on biodiversity; b) how does the impact vary according to the level of multifunctionality of the measures; c) is there a difference in the biodiversity impact of floodplain management across taxa; d) what is the effect of the time since implementation on the impact of the most important measures; and e) are there any other factors that significantly modify the biodiversity impact of floodplain management measures? Within this systematic review we will assess multifunctionality in terms of ESS that are affected by an implemented intervention. Biodiversity indicators included in this systematic review will be related to the diversity, richness and abundance of species, other taxa or functional groups. We will consider if organisms are typical for and native to natural floodplain ecosystems. Specific inclusion criteria have been developed and the wide range of quality of primary literature will be evaluated with a tailor-made system for assessing susceptibility to bias and the reliability of the studies. The review is intended to bridge the science-policy interface and will provide a useful synthesis of knowledge for decision-makers at all governance levels.

Keywords: Biodiversity, Multifunctionality, Floodplain management, Green infrastructure, European Commission Biodiversity Strategy 2020, Biodiversity knowledge, Ecosystem services, Flood prevention, River restoration, Systematic review, Science-policy interface, Science-practice interface

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Background

The European Commission proposed in its recent Biodiversity Strategy to maintain and enhance European ecosystems and their services by 2020 by establishing green infrastructure (GI) and restoring at least 15% of degraded ecosystems [1]. The package of actions designed to respond to this challenge included the need to ensure no net loss of biodiversity and ecosystem services by EU-funded projects, priority setting regarding restoration, and promoting the use of GI [1]. GI is defined as the network of natural and semi-natural areas, features and green spaces in rural and urban, terrestrial, freshwater, coastal and marine areas [2]. This includes for instance areas of high nature value such as protected areas, floodplains, wetlands and natural forests, natural landscape features that can act as corridors for wildlife, artificial features such as eco-ducts or eco-bridges, and multifunctional zones where land uses are favoured that help maintain or restore healthy biodiverse ecosystems [3,4]. The European Commission emphasizes the ability of GI to perform multiple functions in the same spatial area, thus sustaining a range of benefits by delivering multiple ecosystem services (ESS) such as air and water purification and climate regulation [5,6]. ESS represent the benefits human populations derive, directly or indirectly, from ecosystem functions [7], and both functions and benefits might be affected through interventions, such as reconnection of natural areas and improvement of overall ecological quality of the countryside. A combination of the delivery of multiple ESS including the conservation of biodiversity could lead to win-win situations and thus present an efficient way of achieving long-term nature conservation [8]. Knowledge generation to promote understanding of such situations is a current research priority in conservation biology, applied ecology, and environmental sciences [9,10]. Within this systematic review we will assess multifunctionality in terms of ESS that are affected by an implemented intervention.

Floodplains develop adjacent to river channels and can be described as low-relief Earth surfaces composed of fluvial deposits [11,12] that are frequently flooded (active floodplains) or formerly flooded (morphological floodplains) and are an integral part of catchments [13]. While hosting important natural assets and high levels of biodiversity [14-16], they have been used since ancient times by human populations, who attempted to maximize the benefits they gained by interventions such as irrigation channels and dikes [17]. In many parts of the world, human activities have altered the landscape and disrupted fluvial processes to the extent that floodplains are among the world´s most threatened ecosystems [18-20]. Floodplains are good examples for multifunctional landscapes and GI and their management requires close coordination among agriculture, water use, hydrological engineering, mineral extraction, energy production, nature conservation and spatial planning [21] and poses multi-dimensional challenges to policy-makers and project managers [22]. Flood protection is particularly important in light of an increasing frequency and amplitude of flood events throughout Europe, resulting in casualties and damage [23,24]. Restoration of a river and its adjacent floodplain might generate many benefits for nature and society, including alternative economic activities, improved flood prevention, richer biodiversity and aesthetically appealing landscapes and particular recreational opportunities. However, information on implementation and outcomes of such projects is often inaccessible [25].

Evidence for biodiversity effects of the GI approach and particularly of multifunctional floodplain management is scattered and has not been synthesised [21]. This issue is of particular relevance for large lowland floodplains, where due to high human population densities a variety of ecosystem services are in demand while at the same time floodplain biodiversity is driven by dynamic biophysical processes and feedback mechanisms over broad spatial and temporal scales [13,17]. As climate is an important factor for ecological processes, floodplains situated in climates comparable to those occurring in Europe are of particular relevance for this review that aims to support European decision-making. Floodplain interventions are very diverse [26] and in this scientific review we will hierarchically categorize the encountered interventions with respect to their main aims and effects. The interventions also differ strongly regarding the frequency of their implementation and the degree to which their impact on biodiversity has been assessed or results published in accessible formats [25]. This must be considered when interpreting the results of this review. The level of multifunctionality of interventions can be assessed in terms of their effects on ESS. For instance, several restoration measures aiming at a dynamic habitat mosaic are supposed to additionally increase the provision of ESS, such as water purification and lifecycle maintenance, habitat and gene pool protection [13]. Suitable indicators of biodiversity include measures such as the diversity or abundance of species, taxonomic or functional groups [27-30]. The effects of the floodplain management measures on biodiversity will be prone to several factors, the most obvious being the considered taxa and the time since intervention. Floodplain management measures can have very different effects on different taxa, for instance, a water enhancement scheme for the Danube floodplain within the city limits of Vienna showed positive effects on dragonflies and molluscs, while no significant impact was observed for fish [31]. Time since intervention is a crucial parameter, and depending on several factors, such as availability of propagules for population establishment, an intervention might show its effects only after a considerable time span [32].

Objective of the review

In this systematic review we aim to synthesise evidence in response to a two-part primary question dealing with the effects of multifunctional floodplain management on biodiversity. We will further assess three secondary questions dealing with the main causes of heterogeneity in patterns detected.

Primary question

What is the impact of floodplain management measures on biodiversity and how does the impact vary according to the level of multifunctionality of the measures?

The question contains the following components:

Population: floodplains and rivers, including all ecosystems that are located in the morphological floodplain and linked to the hydrological regime of the river.

Intervention: floodplain management measures, commonly related to production and transport (e.g. water or mineral extraction, navigational infrastructure), water regulation and flood protection, conservation and restoration as well as recreation activities (see Methods section for further examples).

Comparator: the previous state of the floodplain before the implementation of the intervention, the original natural state of the floodplain, or the state of the floodplain after another kind of intervention.

Outcome: change in biodiversity indicators (diversity and abundance indicators of species or other groups of organisms).

Secondary questions

a) How does the biodiversity impact of floodplain management differ across taxa?
b) What is the effect of the time since implementation on the impact of floodplain management measures?
c) Which other factors significantly modify the biodiversity impact of floodplain management measures?

Methods

Searches

Database search terms and languages

Three categories of search terms will be applied, corresponding to the categories of the questions, i.e. population, intervention and outcome (Tables 1, 2 and 3). The comparator will not be included for the search itself but as an inclusion criterion. We aim to perform the search in the two main databases for scientific literature, i.e. Scopus and Thomson Reuters Web of Knowledge (formerly ISI Web of Knowledge). The main search terms for each category will be complemented by alternative terms deemed by the review team to have similar significance given the terms have been applied in several key papers [26,33-35]. Among the three categories, the terms will be linked with the Boolean operator 'AND'. Within the three categories, the terms will be linked with the Boolean operator 'OR'. In the "outcome-group", the main search term "biodiversity" will be complemented by a combination of (i) any of the four terms "diversity", "richness", "abundance", and "density" AND (ii) any of many alternative terms for "species", such as "genus", "taxon", "plant", "tree", "bird", "insect", "macrozoobenthos", etc. (Table 3). To be considered, studies will have to contain one term for each of the three categories in either title, keywords and abstract or topic for

Table 1 Search terms for the population "floodplains"

Population		
flood*	oxbow	ripari*
inundat*	river	tributar*

Table 2 Search terms for the intervention "floodplain management"

Interventions		
General terms	habita* renaturali*	water* rehabil*
alluvi* *connect*	habita* restor*	water* renaturali*
alluvi* manag*	in-stream* *connect*	water* restor*
alluvi* measur*	in-stream* manag*	**Specific terms**
alluvi* rehabil*	in-stream* measur*	bank fixation
alluvi* renaturali*	in-stream* rehabil*	bank stabilization
alluvi* restor*	in-stream* renaturali*	boulder additions
aquati* *connect*	in-stream* restor*	channel reconfiguration
aquati* manag*	multifunct* *connect*	connectivity at hydraulic facilities
aquati* measur*	multifunct* manag*	creat* a water course
aquati* rehabil*	multifunct* measur*	creat* of multi* chann*
aquati* renaturali*	multifunct* rehabil*	dam removal
aquati* restor*	multifunct* renaturali*	elong* of river length
channel* *connect*	multifunct* restor*	fish passage
channel* manag*	ripari* *connect*	flow modification
channel* measur*	ripari* manag*	flow regulation
channel* rehabil*	ripari* measur*	install* of flow deflect*
channel* renaturali*	ripari* rehabil*	land acquisition
channel* restor*	ripari* renaturali*	lower* of entrench* depth
floodplain *connect*	ripari* restor*	modifying flows
floodplain manag*	river *connect*	morphological alteration
floodplain measur*	river manag*	reconnection
floodplain rehabil*	river measur*	re-connection
floodplain renaturali*	river rehabil*	reconfiguring river
floodplain restor*	river renaturali*	river continuity
habita* *connect*	river restor*	river widening
habita* manag*	water* *connect*	stormwater management
habita* measur*	water* manag*	water abstraction
habita* rehabil*	water* measur*	wood placement

Table 3 Search terms for the outcome "biodiversity" following the formula "biodivers* OR (group1 AND group2)"

Outcome			
group1-terms			
abundance	density	divers*	richness
group2-terms			
species	***plants***	***animals***	***animals (cont.)***
bentho	*alga*	amphib*	mammal*
family	*annual*	animal*	meiofauna*
fung*	bryophyte*	ant*	mollusc*
genus	*cotyl*	arthropod*	moth*
microorganism*	epiphyte*	avian*	mussel
organism*	fern*	bee*	nematode*
parasite*	forb*	beetle*	newt
pelagic*	grass*	bird*	omnivore*
plancton	liana*	butterfly*	owl*
plankton	orchid*	carabid*	passerine*
saprophyte*	perennials*	carnivore*	pollinator*
species	plant*	caterpillar*	raptor*
taxa	tree*	cricket*	reptile*
taxon		detritivore*	snail*
		fauna	snake*
		fish*	toad
		frog*	tortoise
		grasshopper*	turtle
		grazer*	*vertebrate*
		herbivore*	wader*
		insect*	wasp*
		larva*	woodpecker*
		lizard*	

the Scopus or Thomson Reuters Web of Knowledge databases, respectively.

Thus the total search string will have the following structure:

(Population-Term-1 OR Population-Term-2 OR … OR Population-Term-n) AND
(Intervention-Term-1 OR Intervention-Term-2 OR … OR Intervention-Term-n) AND
(biodiversity OR ((diversity OR richness OR abundance OR density) AND (Outcome-Term-1 OR Outcome-Term-2 OR … OR Outcome-Term-n)))

While the search terms have been developed and will be applied in the English language only, non-English documents returned by these English search terms will be included in the systematic review. No time and document type restrictions will be applied.

Grey literature

We will cover a representative share of European grey literature by a complementary expert assessment. Selected experts from a broad range of European countries will synthesize personal expertise and grey literature for their specific country following a template to specify i.a. the role of multifunctionality in floodplain management and evidence for effects of multifunctional floodplain management approaches on biodiversity. Other ways of dealing with grey literature such as searches in Google Scholar and retrieving a limited number of hits (e.g. 50) as proposed by CEBC [36], seem to be less adequate for our purposes. These seemingly systematic procedures would produce a highly arbitrary selection, because (i) of the breadth of the topic (e.g. all floodplain management interventions, all taxa), (ii) the need for a simple search string, (iii) much relevant grey literature on the topic is written in non-English languages, (iv) much information was never adequately published, partly because commissioned studies were kept confidential or because they are part of larger and on-going floodplain management activities. The complementary expert assessment is almost completed at the time of compiling this protocol and will be published before the systematic review is written up. Consistency and differences of the findings of the two processes will be discussed in the discussion section of the systematic review.

Literature provided directly by stakeholders

Stakeholders were asked beforehand to provide literature. This literature was used to establish this systematic review protocol, but will also be considered for the definitive review. It will be reported, how many of the papers provided by the stakeholders overlap with those of the systematic search and how many of them were deemed suitable for assessment when applying the inclusion criteria.

Comprehensiveness and effectiveness of the database search

We tested the comprehensiveness of the search string in the following way: (i) we agreed on a short list of 6 expressions to be included regarding the population; (ii) we established extensive lists of 86 and 72 alternative terms for intervention and outcome, respectively; (iii) we evaluated the overall hits of the full query in the Scopus database; (iv) we evaluated the specific additional hits provided by each of the intervention-terms while keeping outcome constant; (v) we ranked the intervention terms according to their number of specific additional hits and assessed their cumulative hits by adding them one by one according to their relevance; and (vi) we repeated the last two steps for the outcome-terms while keeping the intervention-terms constant.

Consequently, we found that 37 of 86 terms for intervention (43%) did not yield any specific additional hits, as was the case for 45 of 72 terms for outcome (62.5%). Due to the long and flat plateaus of the saturation curves (Figure 1), we assume that our search string will adequately cover the relative literature. Thus, we will not search bibliographies of selected papers for potential additional literature except for identifiable review articles falling under the scope of this study, which will be searched for relevant primary studies. These primary studies detected in review articles will be treated in the same way as those identified directly by the search strings. The high proportion of alternative terms yielding zero or few additional hits might potentially be caused by having chosen the wrong terms, but this can be considered as highly improbable, because much literature was screened and many experts on the topic have been involved in the compilation of the lists.

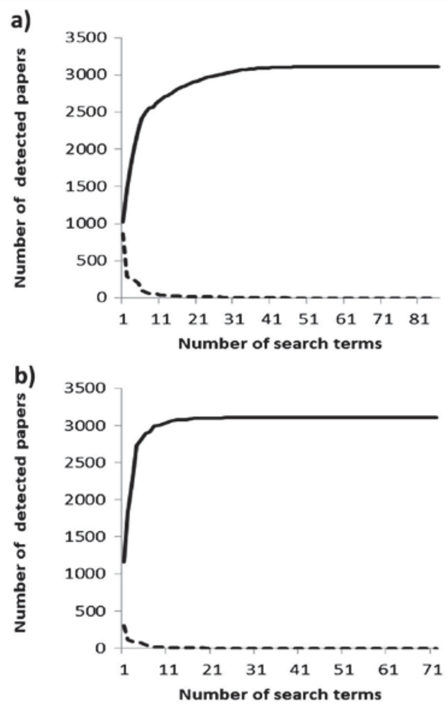

Figure 1 Saturation curves of the test searches for (a) intervention and (b) outcome. Full lines specify the cumulative hits when adding search terms one by one, dotted lines represent the specific additional hits for each alternative term. Terms were ranked according to their number of additional hits. These evaluations were performed with the Scopus database, keeping constant the search terms for the other aspect, respectively, and for "population".

To ensure the review is as comprehensive as possible we opted to keep the alternative terms that did not result in any additional hits in our search string, as keeping them will not require any further effort, but they might yield hits when using other combinations of terms, being translated to other languages, searching other databases or when searching in the future.

Study inclusion criteria and study collection

Articles identified by the search strategy will be filtered during a process consisting of three steps. First the inclusion criteria listed below will be applied to the titles of the studies. Titles often provide enough information (e.g. regarding the population or the geographical location) to clearly recognize incongruous articles which can subsequently be removed. The remaining articles will be filtered by viewing the abstract followed by the full text. Incongruity might occur and be detected in any of the three stages, because a study may obviously not match with the population (e.g. because it concerns a different kind of water body or does not match geographically or climatically), the intervention or the comparator (e.g. no intervention takes place or no comparator is used, while instead the study might describe the ecological status of a floodplain and recommend management measures), or will focus on different outcomes (e.g. geomorphology, water dynamics). If there is insufficient information to exclude a study, it will be kept in the database until the next stage.

To assess and limit the effects of between-reviewer differences in determining relevance, two reviewers will apply the inclusion criteria to a set of randomly chosen articles at the start of the abstract filtering stage. The kappa statistic [37] will be calculated, which measures the level of agreement between reviewers. If kappa is less than 0.6, the reviewers will discuss the discrepancies and clarify the interpretation of the inclusion criteria. This may entail a modification in the criteria specification. After this discussion, the reviewers will apply the inclusion criteria to the remaining articles. Studies reported in articles must achieve the following criteria to be included in the review and used for data extraction.

Relevant population

Floodplains including all ecosystems that are located in the morphological floodplain and linked to the hydrological regime of the river (e.g. rivers, oxbows, floodplain forests, flood-meadows, paddy fields) will be considered. Our focus is on large lowland floodplains and we excluded headwater streams (Strahler's river order ≤ 3) and their floodplains for the purpose of this study. All other kinds of wetlands, such as lakes, estuaries, deltas and tidal flats, peatlands and fishponds [38] will not be considered.

We focus on environmental conditions that prevail in Europe, because this systematic review aims to support

European decision-making. Evidence might come from other continents, but the environmental conditions should be similar to those in Europe. For this purpose, this systematic review will be limited geographically to the areas in both northern and southern hemispheres lying between the tropic and the polar circle, i.e. between 23° 26′ 22″ and 66° 33′ 39″, and climatically to the following Köppen-Geiger climate classes [39]: (i) "Dfc – Snow/fully humid/cool summer", (ii) "Dfb – Snow/fully humid/warm summer", (iii) "Dfa – Snow/fully humid/hot summer", (iv) "Cfb – warm temperate/fully humid/warm summer", (v) "Cfa – warm temperate/fully humid/hot summer", (vi) "Csb – warm temperate/summer dry/warm summer", and (vii) "Csa – warm temperate/summer dry/hot summer".

Types of intervention

All types of intervention related to floodplain management will be considered. Such interventions are commonly related to production and transport, hydrological engineering and flood protection, conservation and restoration or recreation. Specific examples are for instance water extraction, navigational infrastructure, construction of dikes, construction of detention basins, removal of bank fixation, lowering of entrenchment depth, wood placement, installation of flow deflectors, elongation of river length, creating a new water course or multiple channels, extensification of land use and the reconnection of backwaters [26].

Types of comparator

We will only include studies that use comparators, and have identified the following three types when the outcome of interventions related to floodplain management is compared to (i) the previous state before the implementation of the intervention (e.g. [26]), (ii) the original natural state of the floodplain (mainly when assessing the performance of restoration measures, e.g. [40]) or (iii) to the state of a comparable floodplain after the implementation of another kind of intervention (e.g. [41]). Additional heterogeneity in the application of comparators in the primary studies will be caused by the different kinds of study designs (see section "Study quality assessment").

Types of outcomes

To be included, a study must assess the impact on biodiversity. As biodiversity (which implies the entire genetic, species and habitat diversity of an area) cannot be assessed directly, studies will use indicators of biodiversity. In this review, we will consider studies that assess impact on biodiversity expressed by indicators related to diversity or abundance of groups of organisms, such as species, other taxa (e.g. genus, families, subspecies), guilds (e.g. forest birds, rheophile fish), and functional or morphological groups (e.g. shredders, shrubs, macroinvertebrates) [27-30]. Studies that assess genetic and habitat diversity are also relevant, but will be excluded from the study and should be covered by future systematic reviews.

The indicators related to the diversity of groups of organisms include "diversity", which is commonly measured by diversity indices such as the Simpson or the Shannon Diversity Index, "richness", i.e. the number of species, "density", i.e. the number of species per spatial unit, and "evenness", i.e. evenness in number of individuals of each species in the area [42]. The indicators related to the abundance of groups of organisms include measures of abundance and density of specimens [43].

In the frame of this systematic review, we will evaluate for each relevant analyses encountered in a study (hereafter called "case"), whether the groups of organisms considered are specialists related to river dynamics and natural floodplain habitats and classify them accordingly during data extraction and for the synthesis.

Types of studies

We will include all kind of studies containing primary data about the impact of floodplain management on biodiversity (see also section "Study quality assessment").

Potential effect modifiers and reasons for heterogeneity

As we are tackling a broad topic, plenty of effect modifiers and reasons of heterogeneity are anticipated. We will extract several items of relevant information from the studies:

–) General study parameters: country, longitude, latitude, altitude, geographic zone, biogeographic realm, biome [44], Köppen-Geiger climate classes [40], investigated environment (artificial surfaces / agricultural areas / forests / wetlands, semiaquatic, mixed and others (including flooded meadows) / water), years of data collection, Strahler stream order, spatial extent of the study area, naturalness of the study area [45];

–) Methodological variables: the kind of intervention, time since implementation of the measure, study design (cf. Table 4), number of replicates of biodiversity plots per sampling site, sampling method, kingdom (animalia, plantae, fungi, protista, bacteria) and finer taxonomic categories (including functional groups), the size of the species pool (i.e. the number of potentially present species), outcome measure used (species richness, species diversity, etc.), statistical method applied.

Study quality assessment

Study quality assessment is required to add quality covariates to the analyses. Reviewers will assess the methodologies used in all articles accepted at full text. The quality assessment will be based on an evaluation of the following five criteria: (i) study design and repetitions, (ii) appropriateness of methods including statistics, and coverage in terms of spatial and temporal scale, (iii) intervention, intra-treatment variation, and confounding factors, (iv) baseline comparison, and (v) reliability of the study including presentation of consistency of methods and results, and missing values. Study quality will be scored following a hierarchy of evidence based on susceptibility to bias [46-48]. The particular system developed for the purpose of this review was adapted from the study quality assessment implemented by Stewart et al. [49]. Each criterion will be scored by the reviewer, and complemented by a short text specifying the reasons for the scoring. For example, a standardised study design like the BACI (Before/After/Control/Impact) type [50] would be of higher quality than a simpler design applying only spatial but not temporal control. The maximum overall score will equal 100 points (Table 4). The scoring might be different for each 'case' of analyses detected in a research paper, as it might be that sampling effort varies across considered taxa, or that primary analyses and results are presented incompletely for some cases. In the following, specifications of quality issues are presented for each of the five criteria:

(i.) Study design and repetitions are crucial aspects that determine the study results susceptibility to bias, robustness, explanatory power and generalizability [51]. Scoring will follow a scheme that considers study design expressed in temporal and spatial repetitions (Table 4).

(ii.) Appropriateness of methodology, and spatial and temporal coverage: appropriate sampling methods and statistical approaches are required to make best and unbiased use of information gathered. Validity and relevance of study results depends on the appropriateness of methods used and on the appropriate coverage in terms of the spatial and temporal scale of the study.

(iii.) Intervention, intra-treatment variation, and confounding factors: interventions might be badly specified or many different measures might be treated as 'interventions' and compared to control sites. Other confounding factors might lead to the conclusion that the study results might be prone to bias or error.

(iv.) Baseline comparison: in environmental sciences many studies might be confounded in terms of the baseline case selected, because the control sites are too different in regards their ecology or because they had been sampled at a large spatial or temporal distance or even with a different sampling protocol compared to the sampling units subject to interventions.

(v.) Presentation of methods and results, reliability, and missing values: it is impossible to know the rigor that was implemented during all stages of a primary study. However, clarity and thoroughness of the presentation of methods and results might indicate overall scientific rigor and reduce the probability of wrong interpretations by the reviewer. Errors might occur during all stages of a study and confounding statements or very unreliable results in tables and figures that are not mentioned in the text or explained in the discussion, might indicate flaws in data processing or reasoning. Missing results for specific cases can lead to directional bias, for instance when only significant results are reported [52].

Data extraction strategy

Data will be extracted from each article and recorded in a spread sheet. One article can contain several cases of valid and relevant analyses and all of them will be extracted in different spread sheet rows. Data to be extracted will include the intervention and its level of multifunctionality, the outcomes, the methodology and other potentially confounding factors that have been identified as possible reasons for heterogeneity in the primary studies (see above Potential effect modifiers and reasons for heterogeneity).

A major issue in this systematic review is the assessment of whether and how the biodiversity impact of the interventions varies according to their level of multifunctionality. As the multifunctionality of the intervention is not directly obtainable from the primary literature, we will assess the level of multifunctionality for all important interventions based on their average effects on ESS provision. Each intervention might have either a positive, a negative or no influence on the provision of a specific ESS. The matrix concerning this matter will mainly be based on expert evaluations during workshops and teleconferences complemented by relevant information from literature sources. We will also consider ESS that might be related to 'secondary functions' or 'co-benefits' (sensu [53]). For the ESS classification, the "Mapping and Assessment of Ecosystem Services (MAES)"-scheme will be applied, which is based on the CICES classification [54] and has recently delivered its first applicable results [55]. We will consider 21 ESS and calculate for each intervention a multifunctionality index that equals the difference of the number of positively and negatively affected ESS divided by the overall numbers of considered ESS. This index will range between −1 (all ESS negatively affected) and +1 (all ESS positively affected) and interventions with positive values are supposed to increase the level of multifunctionality.

A further important issue is the extraction strategy related to the outcome, i.e. the biodiversity indicators, and we will evaluate for each case, whether the species of an assessed group of organisms are typical for and native to natural floodplain ecosystems.

Data extraction forms will be piloted on a purposive sample of the articles, to represent the range of articles available, and amended if necessary to improve repeatability and efficiency. For most study designs, we expect to extract F, R, R^2 values as well as p-values, sample sizes and degrees of freedom. Special care will be taken with regards potential publication bias that occurs when only significant results are presented in a paper that contains several kinds of analyses (e.g. related to subtaxa, subareas). Missing data for the most important issues (e.g. statistics, sample sizes, degrees of freedom) will be calculated or inferred where possible from the summary statistics presented: if not possible the authors will be contacted. Missing data regarding some of the covariates (altitude, years of data collection, Strahler stream order, etc.) will be researched, after being considered as relevant in the meeting of the stakeholder group.

Data synthesis and presentation

Initially a narrative synthesis of the data will be elaborated, and extracted cases will be grouped into hierarchical categories by intervention, also considering types of comparators, taxa, time since intervention and study quality. The exact categories will depend on the quality and type of data retrieved during the data extraction stage. One focus of the analyses will be on the evaluation of differences in effect size among established intervention types with apparent promise in a European context given their frequency of implementation and evidence from published accounts. The potential influence of the level of multifunctionality associated with different interventions will also be assessed. Additionally, we will test for the effects of the main covariates such as taxonomic kingdom, time since intervention, and habitat investigated. If extracted data are suitable for quantitative synthesis, we will aim to calculate effect sizes and carry out a meta-analysis [56,57]. Sensitivity analysis will be run to explore the effects of including studies with different designs and methodological quality. We will consider the different comparators in different analyses, as effect size has a totally different (even opposite) meaning when the effect of an intervention is compared to a previous unrestored situation or to the situation of a natural remnant. We will limit our analyses in the first instance to cases dealing with specialist floodplain species, and test later whether the same pattern can be detected for generalist species. Non-native species will be analysed separately, if the number of cases is high enough to enable a quantitative analyses.

If insufficient data are extracted, data are mainly of low methodological quality, or if the literature is too heterogeneous in regards to the interventions, we will limit our summary to a narrative synthesis and present the outcomes in tables and eventually systematic knowledge maps. Outcomes from addressing both the primary and secondary questions posed here will be discussed with selected stakeholder groups and implications for multifunctional floodplain management in Europe considered.

Table 4 Scoring sheet for study quality assessment

Bias and generic data quality features	Specific data quality features	Quality element	Quality score
Selection and Performance bias: Study design	Temporal repetition	Before-After (BA) Time Series (>1 replicates before and after)	25
		Interrupted BA Time series (>1 replicates before and after)	20
		BA comparison (1 Before, >1 After)	15
		BA comparison (>1 Before, 1 After)	12
		BA comparison (1 Before, 1 After)	10
		Deficient BA comparison (e.g. Before-data from archives or not from exactly the same sites)	1
		No BA comparison	0
	Spatial repetition	Gradient of intervention intensity including "zero-control"-sites	25
		Site comparison (control/impact-CI)	15
		Gradient of intervention intensity without "zero-control"-sites	5
		Deficient CI comparison (e.g. Control-data from archives or not from the same period)	1
		No CI comparison	0
Assessment bias: Measurement of outcome	Replicates per treatment (number of sites)	Well replicated (>4 replications) objective parameters measured in several floodplain (sections)	20

Table 4 Scoring sheet for study quality assessment *(Continued)*

		Well replicated (>4 replications) objective parameters measured in a single floodplain (sections)	12
		Replicated (1– 4 replications) objective parameters measured in several floodplain (sections)	10
		Replicated (1– 4 replications) objective parameters measured in a single floodplain (section)	6
		Unreplicated observations of objective parameters	2
		Data gathered by expert opinion or questionnaire	0
	Sampling method	Sampling method perfectly appropriate for purpose	2
		Sampling method of restricted suitability	0
	Coverage	Large scale (large plots, long sampling sessions or large overall extent) in relation to study aims and studies organisms	2
		Intermediate scale in relation to study aims and studies organisms	1
		Small scale (small plots, short sampling sessions or small overall extent) in relation to study aims and studies organisms	0
Selection and Performance bias: Baseline comparison (heterogeneity between treatment and control arms with respect to defined confounding factors before treatment)	Sampling	Treatment and control arms homogenous	2
		Treatment and control arms not comparable with respect to confounding factors OR insufficient information	0
	Species composition	Treatment and control arms homogenous	2
		Treatment and control arms not comparable with respect to confounding factors OR insufficient information	0
	Habitat type	Treatment and control arms homogenous	2
		Treatment and control arms not comparable with respect to confounding factors OR insufficient information	0
	Other confounding environmental factors (floods, etc.)	Treatment and control arms homogenous	2
		Treatment and control arms not comparable with respect to confounding factors OR insufficient information	0
Selection and Performance bias: Intra treatment variation (heterogeneity within both treatment and control arms with respect to confounding factors)	Location	No heterogeneity within treatment and control arms	2
		Replicates within treatment and control arms not comparable	0
	Intervention type	No heterogeneity within treatment and control arms	2
		Replicates within treatment and control arms not comparable	0
	Habitat type	No heterogeneity within treatment and control arms	2
		Replicates within treatment and control arms not comparable	0
Reliability of the presented evidence	Overall consistency and clarity of the paper	High	2
		Low	0
	Statistical approaches appropriate	Yes	2
		No	0
	Clarity of the description of the method incl. statistical models used	High	2
		Low	0
	Clarity of the presentation of the results (incl. statistics)	High	2
		Low	0
	Missing values for nonsignificant results causing publication bias	No	4
		Yes	0

Competing interest
No potential conflicts were identified. This systematic review protocol was developed within the EU-project KNEU – "Developing a Knowledge Network for EUropean expertise on biodiversity and ecosystem services to inform policy making economic sectors", funded by the European Commission under FP7 as coordination action (Grant No.265299).

Authors' contributions
SS, MK, KE, SWB, CSZ, AH, CHR and TW carried out the design of the study, performed the review scoping and drafted the manuscript. KH, MH, RK, VM, and SGL participated in the design of the study and commented on the manuscript. MB, FE and SJ commented on the manuscript. LB, GB, VG, SH, AK, KPZ, CD, MP, TvdS and SZ contributed to the design of the study while

participating in the workshops. All authors read and approved the final manuscript.

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Annex C.2 - Expert assessment on biodiversity effects of multifunctional floodplain management

(cf. Chapter 6.3.2)

Multifunctional floodplain management in temperate Europe and evidence for biodiversity effects: an expert consultation

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Abstract

Floodplains are areas of high levels of biodiversity and hotspots in providing ecosystem services, but at the same time often prone to several sources of land use pressure. Multifunctionality is recently proposed as key concept to reconcile biodiversity and ecosystem services with economical interest in floodplains. Multifunctional floodplain management can be defined as management approach aiming at a balanced provision of ecosystem services under efficient use of public funds, serving the needs of the local residents, but also those off-site populations that are directly or indirectly impacted by floodplain policies. In this document we present biophysics and management history of floodplains, as well as examples for recent multifunctional management approaches and evidence for their biodiversity effects. We cover by means of an expert consultation the six temperate Europe countries Ireland, the Netherlands, Germany, Slovakia, Hungary and the Ukraine.

An interesting pattern of regional differences in management goals and approaches was detected. Whereas flood protection is the top priority in floodplain management of some countries, others have a mixed agenda. Multifunctional floodplain management seems to be possible under all strategies but is showing differences in size and number of projects, which is mainly due to different levels of responsibility for water management in the countries, ranging from centralized national responsibility to region provincial governance. Regarding the management approaches, there is a compelling common set of measures all over Europe, targeting not only the restoration of hydrological connectivity at different scales, but also the adaptation and extensification of land use in flood plains as a precautionary principle. Biodiversity may benefit from all these interventions but evidence is rare as only few projects have documented the respective impacts and responses.

We conclude that there is seemingly no alternative to multifunctional approaches in future floodplain management. Integration of all existing uses and demands is essential. In order to make efficient use of the management resources as well as the ecosystem services, win-win-situations need to be achieved and biodiversity has to play a crucial role. Multifunctionality mainly shows success where stakeholders with diverse expertise and interests are involved in all stages of planning and implementation of regarding projects. It is recognized that such participatory processes are beneficial for environmental resource management, but a big gap remains between the rhetoric on participation and the real-life implementation on participatory processes, and administrative structures often support the subsequent standstill.

Introduction

Multifunctional Green Infrastructure is more and more proposed as a solution for halting loss and fragmentation of habitat and for maintaining and restoring ecosystems and their services (COM 244 2011). Green Infrastructure was defined in this context as “an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations” (Benedict & McMahon 2002). Multifunctionality is commonly related to the functions of an ecosystem and to the ecosystem services provided to human populations (MA 2005, Weber et al. 2006). Multifunctional floodplain management can be defined as management approach aiming at a balanced provision of ecosystem services under efficient use of public funds, serving the needs of the local residents, but also those off-site populations that are directly or indirectly impacted by floodplain policies (cf. Recchi et al., 2012).

Rivers, their banks and their floodplains often form hotspots of biodiversity, as these represent places in natural landscapes where elevated availability of nutrients and water meets the typical hydrological and morphological dynamics of rivers, leading to a characteristic mosaic of habitats differing in age, sediment properties, productivity, and colonization density of biota. This habitat mosaic is inhabited by a multiplicity of generalist and specialist species, both terrestrial and aquatic, which often depend on the relative proximity and functional connectivity of various habitat patches (Scholz et al. 2012).

Historically rivers and their floodplains have also served to humans as major axes of migrations, settlement, agriculture, forestry, fishery, industrial development and trade. As a consequence of historical developments, most floodplains are nowadays still subjected to multiple human uses. This is not much surprisingly, since floodplains provide a variety of goods and services and monofunctional management of floodplains is potentially inefficient (Secchi et al. 2012). The majority of original floodplain areas have been hydrologically disconnected from the river by the construction of longitudinal dykes, and are often dominated by intense human uses, such as agriculture, settlements or traffic routes. Moreover, habitat conditions in the remaining active floodplain areas have often been altered by substantial human impacts, such as river incision, river damming, clay deposition, pollution by plant nutrients and chemical contaminants, introduction of invasive species, or by intense forestry. Thus, we see today most floodplains in Europe in a degraded status, especially due to reduced hydromorphological dynamics. This leads to a reduced rate of habitat turnover in floodplain areas, which is followed by a decrease in the richness especially of specialist species depending on the availability of newly formed channel sections and sediment accumulations created by the natural seasonal patterns of high and low discharge levels.

In the last decades, major floods occurring in several major European rivers have triggered additional interest in floodplain areas, as it is now sought to increase or optimize their flood retention capacity. This interest from governmental flood management administrations has opened new perspectives to re-establish hydrological dynamics in floodplain areas that have previously been partially or fully disconnected. In such floodplain management projects, any physical alterations and new management regimes should be agreed with all important users of the respective areas, in order to minimize potential conflicts of development aims. Thus, there is a need to establish and implement multifunctional approaches in floodplain management (c.f. also Secchi et al. 2012), which may present great opportunities to re-activate degraded floodplain areas. However, in many places major target conflicts have not been resolved, thus preventing future-oriented management of floodplain areas, as there is currently no systematic approach available that can be applied to reconciliation efforts with regard to the various competing management goals.

In this manuscript, we assess which interdisciplinary concepts have been developed to create “win-win” situations in timely floodplain management, including substantial improvement of the ecological status of the respective river floodplains. We present the current status of river regulation, examples of best practice of multifunctional floodplain management and evidence for its effects on biodiversity along a gradient through temperate Europe including Ireland, the Netherlands, Germany, Slovakia, Hungary and the Ukraine (fig. 1).

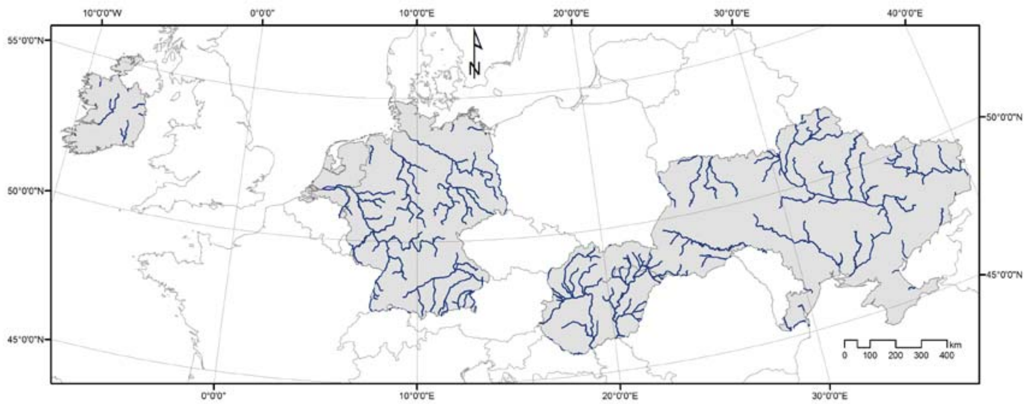


Figure 1. River floodplains in Ireland, the Netherlands, Germany, Slovakia, Hungary and the Ukraine, covered by this expert consultation.

Multifunctional floodplain management in Ireland

Rivers, floodplains, their biodiversity, and their regulation history

There are 13,240 km of surveyed river channel in Ireland, including the River Shannon, the longest river in Ireland and Britain at 361 km. Larger rivers often have extensive floodplains, e.g. Shannon, Lee, Suir, Nore, Barrow, Slaney, Munster Blackwater and Boyne. For administrative reasons Ireland has been divided into 12 river basin districts.

Many of Ireland's rivers, including the eight listed above, are designated under the EU Habitats Directive as Special Areas of Conservation (SACs) for the conservation of fish (Dromey & O'Keeffe 2004). Five species of fish listed in Annex II of the EU Habitats Directive breed in Ireland. These are twaite shad (*Alosa fallax fallax*), brook lamprey (*Lampetra planeri*), river lamprey (*L. fluviatilis*), sea lamprey (*Petromyzon marinus*) and Atlantic salmon (*Salmo salar*). Other aquatic species listed in Annex II that are found in Irish river systems include freshwater pearl mussel (*Margaritifera margaritifera*), white-clawed crayfish (*Austropotamobius pallipes*) and European otter (*Lutra lutra*). Bird species that depend on river systems include the kingfisher (*Alcedo atthis*), which is listed on Annex I of the EU Birds Directive.

Important river and floodplain habitats in Ireland include the EU Annex I habitats 6410 *Molinia* meadows (especially those of the River Shannon Callows), 91E0 Alluvial forests, 1130 Estuaries, 1140 Tidal mudflats & sandflats, and 3260 Floating river vegetation.

Land use developments that affect rivers and their floodplains in Ireland include agricultural intensification, urbanisation and housing developments, tourism and leisure activities, peat extraction and forestry. Agricultural intensification over the last 50 years has resulted in the drainage of wetlands, canalisation of rivers and has contributed to the increased eutrophication of Ireland's rivers. Eutrophication of watercourses can lead to algal growth, which may impact negatively on the survival of species of European importance, such as the freshwater pearl mussel (Moorkens 2000). In recent decades, and especially over the last 20 years, urbanisation and building on floodplains in particular has become a problem, with the destruction of wetland areas and resulting flooding problems for residents in these areas. Forestry and its clear-felling are a problem, as clear-felled areas suffer from soil erosion, with the resulting soil particles washing into river systems. Drainage of bogs, often a precursor to peat extraction, similarly can result in increased siltation into rivers (Moorkens 2000), as can the extraction process itself.

There is a long history of regulating rivers for agriculture, power generation and transport. The straightening and canalisation of rivers and the addition of weirs have commonly been used to control flow and prevent flooding. The canalisation of rivers and the associated dredging and building of earth embankments has greatly reduced the size of river floodplains. There is evidence that watermills were often constructed along Irish rivers and many mill races can still be found today. The two large canal systems linking Dublin to the River Shannon were completed at the start of the 19th century: the Grand Canal was completed in 1804 and the Royal Canal in 1817. Rivers have also been regulated to improve the supply of water to major cities; one of the largest such projects, the Poulaphouca Reservoir, was completed in 1947. Larger rivers such as the rivers Shannon and Lee have also been regulated for hydro-electric power (HEP), with the Ardnacrusha HEP plant built in 1929. The Poulaphouca reservoir on the River Liffey also has the dual purpose of HEP generation.

With the continued growth of the population of Dublin, water shortages have been forecast in the immediate future. To solve this problem there are plans to build a system of canals and pipes to move water from the Shannon river system in the west of the country to Dublin in the east.

Large-scale developments on rivers such as HEP structures pose a considerable barrier to the movement of fish, and even the smaller constructions such as weirs have an impact on the movement of aquatic species (King *et al.* 2011). Also the management of water levels for HEP schemes has been shown to have a negative effect on breeding birds that nest near affected river and lake shores (Mitchell 1990), and on certain plant species, such as *Inula salicina*, a rare species in Ireland that inhabits impacted shoreline habitats (Martin 1998).

Similarly there is evidence that increases in suspended solids, as a direct result of forestry and peat cutting activities, affect key stages in the life cycles of aquatic species (King *et al*. 2011), such as salmon spawning, and survival rates of freshwater pearl mussel juveniles (Moorkens 2000).

River restoration projects, the role of multifunctionality in floodplain management and evidence for effects on biodiversity

To the knowledge of the authors there are only a few Irish examples of river restoration projects that address multifunctionality in floodplain management. The management of floodplains in Ireland is still mainly focused on flood alleviation, with the building of embankments and other flood defences a common approach. There is also still an emphasis on the drainage of flooded areas, rather than reinstating natural wetlands to slow down the rate of percolation of water through the system and therefore to slow down the rate at which the water reaches the rivers. Probably the most common example of multifunctionality is the construction of weirs designed to ensure that they perform the role of water flow control while also facilitating the movement of fish and other aquatic species through the river system.

One of the best examples of an Irish river restoration project is MulkearLIFE (www.mulkearLIFE.com), which aims to restore 21.5 km of degraded habitats along stretches of the Mulkear River, part of the Lower Shannon SAC. The main focus is to provide habitat for sea lamprey, Atlantic salmon and European otter. The project addresses multifunctionality by engagement with fisheries, farmers and the local community in trying to achieve its multiple goals.

In another project in County Kerry, biodiversity enhancement works to the River Lee at Ballyseedy Wood, an Annex I alluvial woodland, were recommended by O'Neill *et al.* (2008). Funding was received in 2012 and the project is expected to lead to improved water quality and enhanced conditions for spawning salmonids, with benefits expected for overall biodiversity and the potential for the return of recreational fishing to the area.

The Lough Melvin catchment management plan (Campbell & Foy 2008) is another project that applies a multifunctional approach, with the main aim being to reduce nutrient levels within the catchment. The management plan has 22 recommendations covering impacts such as agriculture, forestry and wastewater from housing. Some of the most notable recommendations include:

- Education programmes for landowners whose activities impact the environment
- Policies that restrict one-off housing in sensitive parts of the catchment
- Initiatives to deal with alien invasive species such as northern pike (*Esox lucio*)
- Screening of forestry operations in the catchment for appropriate assessment under Article 6 of the Habitats Directive
- A package of agri-environment measures for the Lough Melvin catchment
- Active management of riparian forest buffer zones to reduce the impact of neighbouring clear-felling.

There are few examples that demonstrate the biodiversity effects of multifunctional floodplain management in Ireland. The main reason for this lack of evidence is that the adoption of multifunctional floodplain management in the country is only of recent date. For the last 50 years, agricultural intensification, HEP, and the maintenance of a navigable waterway during the summer have been the main drivers controlling the management of the River Shannon and its floodplain. However, there have been initiatives in the last 20 years to take a more multifunctional approach to management of the Shannon Callows, one of the largest areas of natural floodplain in Ireland. The main reason for these initiatives was the sharp decline in numbers of the iconic bird species, the corncrake (*Crex crex*), from this area. Initiatives such as the Corncrake Project (1991 to 2009), run by BirdWatch Ireland, the RSPB (Royal Society for the Protection of Birds), the National Parks and Wildlife Service (NPWS), and the NPWS farm plan scheme for corncrakes, tried to mitigate against some of the effects of agricultural intensification and to encourage meadow management that favours the conservation of the corncrake.

Unfortunately, the management was often poorly co-ordinated with an emphasis on one outcome, in this case, conservation of the corncrake; bad weather causing prolonged flooding was an additional complicating factor. Recent evidence has shown that the prevention of mowing due to summer floods in 2007-2012, as well as delayed cutting dates for corncrake conservation, resulted in a reduction of plant species richness and community diversity in hay meadows (Maher *et al*. 2011; Maher, in preparation). Preventing farmers from cutting earlier in the year to maintain meadows and improve hay quality also had adverse effects on the corncrake populations, as overgrown meadows do not provide a suitable nesting habitat for the species. Another adverse consequence of the imposed cutting regime was that, in the absence of cutting, some members of the farming community resorted to using chemical herbicides to control vigorous plants such as meadowsweet (*Filipendula ulmaria*); in doing so, they further negatively impacted on all forbs, and plant community richness in general.

The failure to take a truly multifunctional approach to floodplain management therefore resulted in a continued decline in corncrake numbers and negative impacts on biodiversity in general, as well as the alienation of many key stakeholder groups such as landowners, farmers, and nature conservationists. Maher (in preparation) proposes that a more multifunctional approach is required, with the practising of farming methods that incorporate suitable mowing regimes (which control vigorous plants and maintain habitat quality and floristic diversity), while being mindful of the needs of all stakeholder groups.

Conclusions for Ireland

Although it is recognised in Ireland that multifunctional floodplain management is the best way to manage our rivers and their associated floodplains, there are only a few examples of this recognition being put into practice. In the view of the authors there needs to be a more concerted effort by government agencies to promote multifunctional management and to monitor the effects of such management on biodiversity. It is hoped that projects such as MulkearLIFE and the Lough Melvin Catchment Management Plan are the first of many to address the multifunctional management of rivers and their floodplains, so that the long-term benefits that this brings will be clearly evidenced by the enhancement of associated ecosystem services.

Multifunctional floodplain management in The Netherlands

"Thinking of Holland/ I picture broad rivers/ meandering through/ unending lowland" (Memory of Holland, H. Marsman, 1936).

Rivers, floodplains, their biodiversity, and their regulation history

The Dutch live in a river delta. The most important rivers of the Netherlands are the river Rhine (from Bonn onwards the 'Lower Rhine'), with its sources in Switzerland, and the Meuse which springs in France and is mostly fed by rainwater. The Rhine divides in the Netherlands into the Ijssel, the Lower Rhine and the Waal. The length of the Rhine is 1233 km, the Meuse measures some 925 km (Table 1). Other important rivers with smaller catchment area in the Netherlands are the river Eems and Schelde. Being at the bottom end of these rivers has in particular an impact on the Dutch landscape morphology, but also on river dynamics.

Table 1. Main characteristics for the Dutch rivers (management, 2004).

	Rijn	Maas	Schelde	Eems
Length (km)	1.320	900	350	370
Catchment area (km^2)	185.000	32.000	22.000	13.600
Countries in catchment	9	5	3	2
Average discharge (m^3/s)	2200	320	112	78
Peak discharge 1995 (m^3/s)	12.060	2.861		

The rivers Rhine and Meuse developed about 3 million years ago. In the past 2.5 million years glacial periods and interglacial periods alternated. Glaciers from Scandinavia from the Saalien period covered half of the Netherlands and had a large influence on the direction of the rivers. The rivers Rhine and Meuse were diverted to the west. Only later (1000-2000 years ago) the river Ijssel broke through the ice-pushed ridge and formed the northern branch of the river Rhine. In colder periods the rivers changed their route quite often and older river beds often became derelict. The combination of tundra vegetation and hard polar winds resulted in the development of river dunes. In the warmer interglacial periods the polar ice melted and the sea level rose. In this period meandering rivers had curves and often changed their route (Busschers et al. 2005).Today, the Netherlands has a population of some 17 million people and 60% of the Dutch people live 1 to 6.5 m below mean average sea level. The country is slowly subsiding (due to the oxidation of peat, the increase of sea level, and tectonic processes, caused by the melting of the thick Scandinavian ice layer during the last glacial period), and with climate change these processes might become faster (De Mulder et al. 2003, Busschers et al. 2005, Jongmans et al. 2013). This underlines the importance of water management and flood protection. Most rivers and streams fall under the Water Framework Directive (WFD) and most of the riverine areas are also listed as protected areas under the Birds and Habitats Directive. The rivers fall under authority of the Ministry of Infrastructure and the Environment.

The Dutch river floodplains have fertile soils, which are rich in nutrients. Already in the prehistoric period people lived on the higher parts along the river area and there was tillage (Van Beusekom 2007). From medieval times onwards tall fruit tree orchards were planted. In the 1960-1970 period many of them were uprooted for meadows. From 1980 onwards more orchards were established again by the development of low fruit trees which are less labour intensive and more productive. In the lower parts of the floodplains no tillage existed because of the wetness of the soil. Instead of ploughing, meadows developed or, in the swampy areas, growth of willows. Later, the opportunities for tillage in the lower parts improved due to better drainage systems and improved fertilisation methods. Horticulture also occurs on coarse sandy soils with clay substrate in the areas which resulted from a dyke burst (Jongmans et al. 2013). The river area is an important source for minerals. Clay from the floodplains is used for the production of bricks. The winning of clay mostly takes place along the Rhine, the Waal and the Ijssel. Along the Meuse mostly sand and gravel are extracted (De Mulder et al. 2003).

In the last millennium man fixated the rivers in a system of dykes and groynes. The large-scale building of dykes started in the 14th century. Initially, a low embankment was constructed along the border of the river: the summer dyke; its function was to prevent the flooding of floodplain meadows. To prevent larger floods the much higher winter dykes were constructed. At that period dykes were not as strong as they are now: in winter the dykes regularly broke due to stagnant ice (Van Beusekom, 2007). In this period land use evolved as described above. Human encroachment and construction of dykes in the period 1850-2000 resulted in a restriction of discharge capacity and a loss of water storage area.

Initially land use was mostly grazing and fruit production. Nowadays it is mostly mixed land use with grazing meadows and ploughed fields. After the 1953 flood, flood risk and safety standards were established, which were implemented in policy in 1958. The safety standards were particularly focused on the sea defence and tidal areas in the Dutch delta. The Delta Plan, for which the first ideas were conceived in 1937, was launched, which closed off all river arms from the sea with large dams. This also marked the start of Dutch civil engineering. However, after a near-flood event in 1995 there was an urgent need also to reinforce inland river dykes, and the standards were raised to plan for more realistic flood events. This initiated a programme to reinforce the inland river dykes; the so-called Committee Boertien advised on an extensive programme. Also, at that time a debate started on development of water retention areas in periods of high floods. Due to sea level rising and increasing discharge of the rivers, in 2008 the second Delta Plan was launched to prepare the Netherlands for the effects of climate change.

River floodplains are very important for biodiversity: as habitat, and as corridor. The habitat function under natural conditions is very important, due to river dynamics which result in a mosaic of floodplain habitats at a small scale, with large natural dynamics (Romanowski et al. 2005, Romanowski 2007, Van der Sluis et al. 2007). However, the corridor function is also very important, since rivers pass, with their wide variety of habitats, through different landscapes over long distances (Van der Sluis et al. 1999, 2004, Romanowski et al. 2005).

The biodiversity of the Dutch floodplains is impoverished, due to limited natural dynamics and a history of intensive land use. The rivers were important for industry due to their transport potential and the presence of industrial water. This resulted in severely polluted water for many decades, in particular in the 1960s and 1970s from France and Germany, but also as a result of disasters and accidents. Floodplains still have a high contamination rate from pollutants such as heavy metals and PCBs. The transport function of the river in combination with flood protection measures resulted in decreased natural dynamics where the river was managed to optimize transport and to minimize flood risks. Land reallotment added to the decline of biodiversity by drainage of marshland and removal of old parcel boundaries, in particular hedges and tree rows, typical of the riverine landscape which lost its function in the last century (Agricola, 2011 p. 393) The resulting landscape could be considered 'bare' and stripped.

Over the last two decades the approach towards floodplains changed, and biodiversity is now an important driver for river regulation programmes as described above. Another important function is tourism. The overall aim is to increase multifunctionality, with flood protection and increasing biodiversity among the most important functions (Van der Sluis et al. 2001, Geilen et al. 2004). In the same period, water quality improved significantly as a result of international cooperation such as the

International Rhine Committee and by the raising of environmental standards. As a result, biodiversity is currently increasing for most areas. A biodiversity monitoring programme for the River Rhine and Meuse shows for most areas a positive change in biodiversity for most taxa (Kurstjens and Peters 2011, 2012a,b). Even species which were extinct have returned, such as the Atlantic Salmon (*Salmo salar*), for which conservation plans were implemented and many rivers were made passable (Ottburg, in Van der Sluis et al. 2004)

River restoration projects, the role of multifunctionality in floodplain management and evidence for effects on biodiversity

Planning for more natural floodplain development began in 1986, when landscape architects and spatial planners launched the development plan 'Plan Stork'. This plan set into motion a school of planners with ecologists that promoted multifunctional floodplain management. The WWF Netherlands adopted this approach and a foundation 'Ark' was established with the aim of restoring natural processes, and the programme was in line with the Dutch conservation programme (Kurstjens and Peters 2012b). In 1993 and 1995 the water levels were extremely high and the dykes just withstood the flood. A quarter of a million people had to be evacuated. Extreme high river discharges are predicted to occur more frequently in the future and therefore it was decided to increase the discharge capacity of the rivers. The Government approved the Room for the River Programme in 2007 for the Rhine. This plan has three objectives:

1. by 2015 the branches of the Rhine must be able to cope with a discharge of capacity of 16 000 m^3/s water without flooding;

2. the measures implemented to increase safety must also improve the overall environmental quality of the river region;

3. the extra room for the river, required to cope with higher discharges, will remain permanently available.

In total, nine options are considered to enlarge riverbed and floodplains, including dyke relocation, depoldering, and water storage (figure 2). Of the 700 potential projects that were identified in the area of the Rhine and the Ijssel, some 39 were selected, with 35 projects due to be implemented in the period 1995-2015. In the same period a programme started for the River Meuse: the Meuse Works Programme, which was officially initiated in 1997 and scheduled for completion by 2018. The aims were similar for the Meuse: fewer floods, better navigability, and a more natural river valley. The works in particular aim to widen the river bed. In total, 1800 ha are to be converted to nature restoration areas, and 52 projects are or have been executed in the River Meuse area http://www.rijkswaterstaat.nl/water/plannen_en_projecten/vaarwegen/maas/maas_maaswerken/ . The projects involve fewer engineering works and focus on dyke improvement, tourism and grazing management (Table 2).

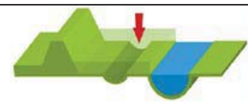
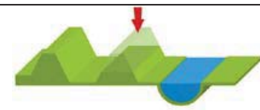
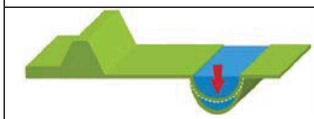
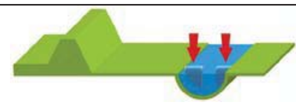
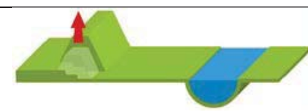
 Dyke relocation By relocating dykes, the floodplains become broader and the river gets more room.	 Excavation off the floodplain By digging off parts of the floodplain the river will get more room at high water level.	 Depoldering The dyke on the river side of a polder is moved inland. This polder is then 'depoldered' and the water retention capacity increases during floods.
 Lowering of the summer bed The river bed is deepened by excavation of the river bed. The riverbed is deepened and there is more room for the river.	 Lowering the groynes Groynes direct the river bed and maintain a certain depth for the river. At high water levels groynes raise the water level. Water can be discharged faster by lowering the groynes.	 Removing obstacles By removing or adjusting obstacles where possible, the discharge of water to the sea is faster.
 Water storage A certain area is reserved for water retention to level off the peaks during extreme floods.	 High water channel A high water channel is a dyked channel, which is opened to discharge part of the water faster during extreme flood events (every 80 years).	 Dyke improvement The quality of the dyke is improved to withstand floods.

Figure 1. Nine approaches of river restoration by reconstruction of the river floodplains and the river bed (based on: 'Room for the River' Programme: http://www.ruimtevoorderivier.nl

Measures are often combined for the project areas, based on site-specific opportunities and river morphology. Practical examples of projects are presented in Appendix 1. It is important to design the measures based on a solid system analysis that considers hydromorphological processes, the built up landscape, and the 'genius loci' (Kurstjens and Peters 2012b).

Table 2. The estimated impacts for the different measures of the 'Room for the River' Programme.
+ = positive, +/- = both positive and negative, 0= neutral, - = negative

Measure	Expected Impact					
	Number of projects (Rijn & Ijssel)	Multi-functional use	Bio-diver-sity	Natu-ral dyna-mics	Land-scape diver-sity	Flood pro-tec-tion
Dyke improvement	7	0	0	0	-	+
Lowering of the summer bed	1	0	0	0	+/-	+
Lowering the groynes	3	0	0	0	0	+
Water storage	1	+	0	0	0	+
High water channel	1	-	0	0	-	+
Excavation of the floodplain	12	+	+	+	+	+
Dyke relocation	5	0	0	0	+/-	+
Depoldering	2	-	+	+	+/-	+
Removing obstacles	1	0	0	+	+/-	+

Other factors in the success of the projects are the coalitions that were forged mainly with the mineral extraction industries, in particular the clay digging companies (for bricks and tiles), and gravel and sand (building materials, road construction). The revenues gained by some provinces were successfully invested in nature restoration plans. From a conflict model, conservation moved towards a cooperation model: discussions were held on where to extract, and under what conditions. Most importantly, after extraction of the clay, sand and gravel pits had to be landscaped and measures were taken to facilitate both ecological processes and tourism development. Economical considerations were also taken into account (Kurstjens and Peters 2012b).

Projects along the River Meuse began in 1995. There were high floods in December 1993 and January 1995, which triggered a flood defence programme aimed at increased safety with more natural floodplain development. Nature restoration projects along the Meuse were executed from 1995 onwards (Kurstjens and Peters 2011). The Meuse floodplains changed from an area which was mostly farmed or used for mineral extraction (sand, gravel) to a much more multifunctional area aiming at flood security, natural functions and recreation. In particular soil was extracted for reinforcement of the embankment in such a way that conditions were optimal for nature to develop. The extent of natural habitats increased from 100 ha in 1990 to 1500 ha in 2006 (Kurstjens and Peters 2011), and the number of such areas increased from 4 to 42. The overall aim is to allow for more natural dynamics, in particular flooding, river morphological processes, seepage and grazing. An evaluation showed the following success factors for nature restoration (Peters, 2008; Kurstjens, 2011):

- Of the flora some 40% of the plants benefited from the creation of floodplain meadows, scrub, and forest on former farmlands
- Increased river dynamics resulted in new habitats as well as the establishment of new plant populations
- Through excavation pioneer situations were created
- Climate change positively contributed to the expansion of species
- Dispersal of seeds by large grazing animals
- Improved water quality for aquatic species

We observe a strong increase in overall biodiversity along the rivers, as a result of the river improvement programme such as 'living with floods' (Kurstjens and Peters 2012a). There was a strong increase in the riverine flora, especially on locations with a sandy soil. Sand dynamics are the crucial factor here. While increased dynamics also resulted in loss of critical species which depend on stable situations, the overall impact was an increase in species diversity.

Important mammal indicator species returned such as Eurasian Beaver (*Castor fiber*), European Otter (*Lutra lutra*) and European Badger (*Meles meles*), which were absent from the rivers since the 1960s, or extinct in the case of the Beaver. For birds, the situation of pioneer species as well as species from softwood and hardwood forests has improved significantly, as have colony breeders. However, marshland and farmland birds have not recovered yet or are still declining, despite active restoration plans (Kurstjens and Peters 2012a). Of the amphibian species the Great Crested Newt (*Triturus cristatus*) still occurs along the different branches of the River Rhine (Creemers 1994). Among reptiles, the Grass Snake (*Natix natrix*) shows a positive trend along the Lower Rhine and has established viable populations in the natural floodplains. The populations of fish of running water are increasing because of the improved water quality of the Rhine and the construction of side channels. Recovery of butterflies is slow; the two areas with the highest species density are the Blauwe-Kamer and the Duursche Waarden (see Appendix 1 for description). The number of dragonflies has much increased due to the improved water quality, climate change and increased biotope diversity, especially in the Blauwe Kamer and the Duursche Waarden. Grasshoppers have also benefited. For some species climate warming is the most important factor in recovery (Warren et al. 2001, in Vos et al. 2008).

- ***Conclusions for The Netherlands***

The Netherlands have a long history in water management, and have always had to cope with flooding. The more recent flood in 1953 was the impetus for a large flood defence programme (the Delta plan). In 1995, a quarter of a million people had to be evacuated due to a near-flood event that initiated a programme to reinforce the inland river dykes and to create water retention areas for high floods. Extreme discharges are predicted to increase in the future and therefore it was decided to increase the discharge capacity of the rivers. The Government approved the 'Room for the River' Programme in 2007, which is a prolongation of the Rhine Flood Protection Programme and the Meuse Works Programme, and is scheduled to be finished by 2018. In 2008 the second Delta Plan was launched which stipulates that each year a Delta programme has to be written consisting of concrete measures to cope with the effects of climate change. Measures are also taken through the WFD to improve water quality and reference values. Multifunctional floodplain management is strongly connected to flood safety.

Combining water safety policies, river restoration programs and the WFD has resulted in an advanced stage of 'eco-engineering' in the Netherlands. A solid system analysis forms the basis for well-designed and well-targeted measures. The approach towards floodplains changed, water safety programmes became policy and nature restoration measures are an integral part of economic development programmes. The measures resulted in higher biodiversity and ecosystems which are characterised by more (natural) dynamics. A success factor in the project was the coalitions that were forged between mineral extraction industries and nature conservation. The revenues gained by some provinces were successfully invested in nature restoration plans. Conservation moved from a 'conflict model' towards a cooperation model, discussions were held on where to extract minerals and under what conditions. Most importantly, after extraction, the clay, sand and gravel pits had to be landscaped and measures were taken to facilitate ecological processes and tourism development.

Multifunctional floodplain management in Germany

Rivers, floodplains, their biodiversity, and their regulation history

There is a wide range of different river and floodplain types in Germany, from high mountain streams to lowland rivers, covering multiple types of uses of both water and riparian areas. Some rivers and floodplains in Germany are still hotspots of biodiversity but their value is slowly but steadily decreasing in nearly all parts of the country. During the last centuries and in the course of hydrological disconnection and channelization, floodplains in Germany have largely decreased. On a national level, just one third of the former floodplains still exist. In some catchments – such as the Rhine, Elbe, Danube and Odra – only 10-20% of the former floodplains are left (Brunotte et al. 2009). Recently, a couple of restoration projects have been established and could serve as pilots for larger-scale planning.

In Germany, the pressure of agricultural land use, especially for biomass production, has increased significantly. Also recreational use of floodplains is still increasing in many parts of the country, possibly paving the way for a better public understanding of the value of floodplains and rivers. However, the destruction of floodplain habitat is still ongoing, triggered by industrial demands, road construction and flood protection measures such as widening and heightening of dykes. Floodplain forests are largely managed for timber extraction and there are only a few near-natural stands left. Thus, almost all natural floodplain forest types are suffering from loss of dynamics. Also wetlands in floodplains (wet meadows and grazing areas) have been largely removed or severely altered through intensive agricultural use. On the other hand, the current restructuring of the classification of navigable waterways for political and financial reasons might present opportunities for ecological development of certain river and floodplain areas.

Local activities started long before the Middle Ages until 1800, but were scattered and mainly around settlements. They have been carried out mostly for the purpose of flood protection of settlements and agricultural areas. Systematic works began around the 1820s with conceptually laid out river bed fixation, and cut-off of side channels, oxbows and meanders, often backed by dyke construction (e.g. Tulla's "First Rhine correction" 1828-1878). It was the growing importance of steam boat navigation that triggered the second phase of corrections with the aim of establishing a stable and constantly sufficient water level in the fairway. Measures included groynes and weirs, bank revetments and training walls. Modern river correction was determined by new construction technologies and capabilities, optimizing the waterways for larger navigation capacities and (on the Rhine following the Treaty of Versailles) for the increasing importance of hydropower use.

River restoration projects, the role of multifunctionality in floodplain management and evidence for effects on biodiversity

River restoration occurred mostly through the implementation of smaller projects along less major rivers and streams within the regular river maintenance (Gewässerunterhaltung). A number of large projects have been carried out which tackled different aspects at a time, mostly flood protection and nature conservation, e.g. Elbe, Danube, Rhine (mostly in connection with the Water Framework Directive (WFD)), and recreational areas, the latter often in urban areas (e.g. Emscher project, Isar in Munich).

On a national level, the Federal Agency for Nature Conservation has financed restoration projects for about 15 years in order to enhance both nature conservation and flood protection. Moreover, a number of federal state programmes have been implemented primarily to increase the level of flood protection, especially with regard to climate change aspects. Nature conservation aspects are included to different extents in such programmes. For example, the Integrated Rhine Programme of Baden-Wuerttemberg started out as a combination of flood protection and floodplain conservation; the latter aspect has unfortunately been somewhat abandoned in the course of the programme.

Synergic environmental benefits of river and floodplain restoration e.g. mitigation of flood risk or of consequences of climate change, are far from being fully exploited and multiple environmental effects are still neglected. The ecosystem approach can help to provide a long-ranging delivery of natural resources and services depending on their sustainable use (Symposium “Biodiversity of surface waters, floodplains and groundwater”, BMU 2008[14]).

Conflicts on future floodplain management regimes have emerged in cases where flood managers planned to use near-natural floodplain areas as managed flood retention polders, which would involve the targeted, rapid filling of floodplain areas with water abstracted from the river during the peak phases of floods. Hydrologists consider this type of targeted polder filling as the most effective way of lowering peak flood levels in downstream sections of a river. Such polder filling is accompanied by rapid increases in water levels in distinct floodplain areas enclosed by dykes on all sides with no significant throughflow of water. Such polder management of floodplains will not substantially improve the typical habitat dynamics of river floodplains, as sedimentation processes will prevail. Hence, it is feared that the specific species inventory of floodplains will not significantly benefit from polder management, and detrimental effects may even occur.

There is very little evidence concerning the large number of (mostly smaller) projects. Local effects have certainly been achieved but unfortunately, monitoring efforts mostly lag far behind the intended and needed extent.

In a research project commissioned by the German Federal Agency for Nature Conservation (BfN,) the ongoing floodplain restoration projects were analyzed. The results reveal that restoration projects have been realized within some 5% of the river floodplains in Germany. These cover about 40 projects alongside bigger rivers, in which approximately 4000 ha of floodplains have been

[14] Symposium: Biodiversity of surface waters, floodplains and groundwater / BMU (Hrsg.) / Bonn / 2008

reconnected by dyke and dam relocation in the last 15 years (BfN 2013, unpublished study). Unfortunately, there is yet no suitable systematic study of the various restoration projects within smaller streams and catchments. Nevertheless, there is clear evidence that, due to restoration and subsequent management changes, the biodiversity value of the restored floodplains increased significantly (Lüderitz et al. 2011). In this study, the development of biodiversity of a large-scale river restoration project with a restored section of about 18 km was compared to adjacent non-restored sectors. The study showed that species number was twice to three times higher in the restored reaches. This increase applied to all taxonomic groups, but was particularly significant for Odonata, Trichoptera, Plecoptera and Ephemeroptera (Lüderitz et al. 2011). Hence, multifunctional floodplain management and especially the restoration of floodplains should be regarded as one of the most important measures where increasing biodiversity value of floodplains is concerned.

However, far more research is needed to analyze, monitor and evaluate further biodiversity effects of multifunctional floodplain management.

Conclusions for Germany

It should be noted that presently multifunctionality is poorly represented in the management of floodplains in general. Programmes and measures which are mostly initiated by governmental institutions are reflecting the sectorally organized structure of the public administration: entities responsible for water management are largely focusing on their respective goals (e.g. flood protection, land use, navigability). Measures initiated by conservation units are focusing mainly on preservation issues rather than on integrated landscape development. This has changed to some extent with the implementation of the WFD, but there is still a general lack of interdisciplinary measures, and this is unlikely to improve in the face of tightening budgets and reduced resource allocation.

The scarcity of multifunctional approaches is also reflected by the lack of large-scale vision in the management and use of rivers and floodplains. Nobody feels the responsibility to create such visions beyond county, federal or national boundaries, integrating all disciplines and stakeholders over extended areas, such as the floodplains of a whole catchment or at least significant functional parts of it. Since there is hardly an institution with responsibility for such areas, the resulting lack might not be too surprising. In order to make full use of synergies and for the establishment of sustainable and efficient solutions, this should be addressed. Entirely new initiatives would probably be needed to bridge institutional, administrative and other boundaries in order to achieve far-reaching cross-compliance.

Multifunctional floodplain management in Slovakia

Rivers, floodplains, their biodiversity, and their regulation history

Slovakia has a dense network of streams; its territory is crossed by the main European watershed between the Black Sea (96% of the Slovak catchment area) and the Baltic Sea (4% in northern

Slovakia). There are 32 rivers and thousands of small rivers and brooks. There are also a number of rivers that only flow thorough Slovakia. The total length of the rivers is 44 943 km. The largest rivers are the Danube and its tributaries Morava, Váh, Hron, Ipeľand and Tisa. The vast majority of water is drained by the Slovak rivers into the Danube, the largest central European river, which flows through 153 km of southwest Slovakia and for the most part forms the border with Hungary. The eastern Slovakian streams supply the Tisza River in Hungarian territory, which disembogues into the Danube in Serbia. The Váh (406 km), the Hron (298 km) and the Nitra (193 km) are the longest Slovak rivers.

Biodiversity related to rivers is rich and varied. There are thousands of taxa of vascular and non-vascular plants, vertebrates and invertebrates, many of them listed in Annex II of Council Directive 92/43/EEC; e.g. the plants *Marsilea quadrifolia, Apium repens, Ligularia sibirica, Trapa natans* and *animals Lutra lutra, Castor fiber, Haliaeetus albicilla, Ciconia nigra, Gobio kessleri* and *Sabanejewia aurata*. Floodplains and rivers host some of the most valuable natural heritage in Slovakia including fifteen NATURA 2000 sites (Stanová & Valachovič, 2002). Lowland floodplain habitats are confined mainly to the larger rivers with wide and slow flow: Watercourses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation (3260); Hard oligo-mesotrophic waters with benthic vegetation of *Chara* formations (3140); Muddy river banks with *Chenopodion rubri* p.p. and *Bidention* p.p. vegetation (3270). Grassy and herbaceous formations including meadows with high diversity of vascular plants are represented by: Hydrophilous tall herb fringe communities of plains and of the montane to alpine belts (6430); *Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*) (6410); and Alluvial meadows of river valleys of the *Cnidion dubii* alliance (6440). Forests are represented almost entirely by the priority habitats, which were strongly impacted by anthropogenic pressures, and in many places are found only as small fragments. The most important are: Mixed ash-alder alluvial forests of temperate and Boreal Europe (*Alno-Padion, Alnion incanae, Salicion albae*) (91E0*); and Riparian mixed forests of *Quercus robur, Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers of the Atlantic and Middle-European provinces (*Ulmenion minoris*) (91F0).

Demography and land use development in Slovakia was significantly associated with watercourses since the Paleolithic period. First settlements in the Mesolithic and Neolithic followed alluvia of rivers in lowlands and uplands. Today, approximately one third of the 5.4 million habitants of the Slovak Republic lives in close proximity to rivers, and almost all of the biggest cities and towns lie on rivers, including the capital city Bratislava on the Danube river, Košice on the Hornád river, and Banská Bystrica on the Hron river.

Within the process of infrastructural and housing developments in Slovakia there has been a loss of agricultural and arable land to forests (Klinda et al., 2010). Since 1990, several protected areas were established for the purpose of floodplain protection, though these efforts were often hampered by the construction activities associated with new houses and logistic centres. Therefore, there is an urgent necessity for sustainable land use development which in Slovakia is only in its early stages. Agricultural soils are still contaminated at the level of the early 1990s, and must be further monitored (Klinda et al., 2010). Approximately 40% of all agricultural land is threatened by water erosion and about 5% is threatened by wind erosion. Anthropogenic pressure to use soil for purposes other than its primary production and environmental functions is detrimental.

Direct systematic human interventions into the channels of major Slovak rivers date back to the 1770s, primarily in order to improve navigability and facilitate river transport. The earliest structures of erosion control and flow diversion represent wicker works, fascines, cut trees serving as breakwaters, groynes and bank revetments (Lukniš 1951, Horváthová 2003, Pišút 2006). In Slovakia, almost one tenth of its territory (4 500 km^2) has been drained, followed by the construction of water works, regulation of water flow and exploitation of peat, and subsequently leading to the disappearance of wetlands and water ecosystems. This phenomenon is accompanied by the eradication of numerous organisms and the loss of rare functions which contribute to the preservation of the ecological balance (Klinda et al., 1998).

The most important fluvial system of the Slovak Carpathians is the gravel-bed Váh River, the longest river of Slovakia (403 km), with Q_m=196 m^3s^{-1} at its confluence with the Danube River. At present, most of the Váh River valley is regulated with canals, artificial dams and 22 hydropower stations (known as the Váh Cascade). Prior to regulation, the Váh was a high-energy, wandering river along its middle and upper reaches, while along its lower reaches it was a laterally unconfined, actively meandering river. Heavy bank erosion caused numerous and often catastrophic landslides along a 17 km-long stretch (Lukniš 1951).

The best-documented examples of the most recent human impacts on fluvial systems are from the Morava and Hron Rivers, which were straightened between 1930 and 1960 (Holubová et al., 2005). The Morava is a characteristic medium-energy river with a fine-grained bed and relatively cohesive banks. Prior to regulation, the Morava at its lowermost reach was an actively meandering, single-thread river (Grešková 2002). Between the 1930s and 1960s, the lower Morava was shortened by more than 10 km by cutting off 23 meanders. The present day channelized Morava is a low-sinuosity river with lateral migration mostly prevented by bank revetments. The synergistic effect of increased slope, sediment discharge deficit and gravel extraction induced bed degradation, locally up to 2 m (Grešková 2002).

The Hron is the second longest Slovak river (279.5 km). The Lower Hron is flanked by higher terrain and has no continuous flood dykes. It was artificially straightened, decreasing the length from 80 km to 74.5 km. In contrast to the Morava River, the channel still maintains a certain degree of freedom to migrate, although flow dynamics and sediment transport are influenced by small hydroelectric power stations. The Hron River has coarser bed material and bed armouring. The high loess pseudoterraces along the river show major bank failures, resulting in higher concentrations of suspended load and rapid sedimentation in the cut-off meanders (Holubová et al. 2005).

The Danube formed the largest alluvial fan in Slovakia. Fluvial processes show great dynamics, although it is currently largely determined by engineering structures and dams. Between 1378 and 1528 AD, large avulsions on the Danube River resulted in the abandonment of the 24 km-long lowermost stretch of the Dudváh River (Pišút 2006). In the past the key mechanisms of the Danube channel change were meander development through progression, neck, and chute cutoffs, abandonment of secondary channels and a tendency for channel switching. At Bratislava the floods of the 1760s-1770s triggered a series of channel adjustments and subsequent human interventions, leading to permanent instability of the river channel (Pišút 2002). The modern Danube is the result of the mid-flow channelization in 1886-1896, present-day fluvial processes of the Danube are restricted to the riverbed and the floodplain area between the embankments (Szmańda et al. 2008). The sediment transport through the Slovak section of the Danube has been recently affected by the hydropower plants Freudenau (at Vienna, Austria) and Gabčíkovo (Holubová, 2000).

River restoration projects, the role of multifunctionality in floodplain management and evidence for effects on biodiversity

Conservation of inland water ecosystems is one of several activities within the implementation of the Convention on Biological Diversity and Ramsar Convention. Besides the National Biodiversity Strategy and its components related to ecosystem protection, Slovakia additionally adopted a National Programme on wetlands (according to the Ramsar Convention) and a programme on the restoration of river banks. An Integrated River Basin Management and Land Restoration Programme has been implemented in Slovakia. Restoration of water courses, bank vegetation and natural water regimes was also performed, and the following activities were implemented within the Ramsar Action Plan (Action Plan 2008 – 2011 in the frame of the updated Programme on Wetlands in Slovakia 2008 – 2014): (i) approving the Programme on Landscape Restoration and Integrated River Basin Management of the Slovak Republic; and (ii) preparation of the project proposal related to the State Nature Conservation of the Slovak Republic for the Swiss Financial Mechanism including restoration measures in selected degraded and vulnerable wetlands.

One of the successful projects dealing with the floodplain restoration was *Conservation and management of Danube floodplain forests* (LIFE03NAT/SK/000097). The objective was to preserve the last remaining natural floodplain forests in the Slovak part of the Danube floodplain and to introduce sound, sustainable forest management in the area (BROZ, 2003). Project actions were focused on halting the loss of natural floodplain forest habitats caused by forestry activities by means of different remedial actions, such as improving forest management plans, applying ecological forest management measures, planting of native trees, designation of new nature reserves, land purchase and lease for nature conservation purposes and raising awareness of the general public, key stakeholders and decision makers.

The management of floodplains in Slovakia has long roots in history. Floodplains were traditionally used by local farmers as meadows and pastures. Today, some parts have been ploughed and turned into arable fields. The productivity of these fields is several times lower than the production from meadows (Šeffer, Stanová 1998). Land use practices are not sustainable, and the intensive agricultural practices and development of industry caused the pollution of the river and its tributaries (Šeffer, Stanová 1998). The role of multifunctionality in floodplain management is more evident in the larger rivers with extensive alluvia; moreover, all large rivers in Slovakia are lowland watercourses flowing through big cities and towns. One of the most important European rivers, the Danube, plays a very important role in Slovakia: (i) Danube hydropower produces 12% of the energy demand of Slovakia, (ii) the Danube is an irreplaceable traffic artery, (iii) its floodplain provides flood protection, (iv) it creates conditions, e.g. in terms of the water regime, for declaring protected areas such as the Protected Landscape Area Dunajské Luhy, (v) it creates the possibility of using inundation areas to create a natural flow regime and preserve the old riverbed for converting floods (Lisický & Mucha (eds.) 2003), (vi) it guarantees important purification processes in the Danube section of Bratislava, and (vii) it creates conditions for recreation and tourism such as cycling and other sports or the use of natural ponds for swimming. The Váh River, through “the Váh cascade” consisting of 13 hydroelectric dams, provides a significant supply of electric power in Slovakia; however, flood protection is also an important issue, as well as water provision for irrigation of agricultural areas, and creating opportunities for tourism and recreation. On the other hand, 90% of the river is regulated, with negative effects on the habitats belonging to the floodplain.

The floodplains represent natural heritage and are very valuable areas in terms of biodiversity; in Slovakia there are two large floodplain Protected Landscape Areas (PLAs) in Slovakia (Latorica and Dunajské Luhy), 14 Ramsar sites and more than 200 small-area Protected Areas – National Natural Reserves, Natural Reserves and Protected Areas. The management here is regulated by the legislative acts – laws and regulations. According to multifunctionality – the biodiversity protection is of the highest importance, but also important are recreation and tourism using marked trails, as well as bathing and sailing in PLAs. The effect of such management on biodiversity is conditioned by the legislation; the biodiversity is threatened mainly by the behaviour of visitors, e.g. trampling, collecting of plants and animals.

On a general level, several theoretical studies concerning the issue of monetary valuation of environmental goods and services have been carried out. The use of biodiversity, natural habitats and protected areas to produce environmental goods and services is multifunctional. For example the Morava floodplain is used for hay production, pasture grazing, recreation and angling (Rybanič et al., 1999). One of the best examples in Slovakia is a valuation study conducted on a complex of floodplain meadows in the Slovak part of the Morava floodplain. The assessed regularly cut meadows have an area of 1 727 ha. As a general framework for obtaining a value of the benefits from the conservation and restoration of the Morava floodplain, the concept of Total Economic Value (TEV) was used with direct and indirect use values. The main categories of floodplain management are:

1. Hay production: The production of hay is a traditional form of agricultural management in this area. Farmers usually mow meadows once or twice a year depending on flood conditions. The effect on biodiversity is significantly high: regularly mowed meadows maintain high vascular plant diversity including rare and endangered species.
2. Nitrogen abatement: This was calculated as the substitute market approach. This function depends on the natural water regime of the floodplain; the effect on biodiversity through preservation of suitable niches is undoubtedly high.

The creation and restoration of wet grasslands has become increasingly important following alarming biotope declines in many countries (José et al. 1999). After 1990, the Administration of the Protected Landscape Area Záhorie pushed for arable fields in active floodplain areas to be restored back to meadows. The main reasons for restoration were to increase biodiversity and to decrease river pollution (Šeffer et al., 1999).

The Morava River inundation area represents a river plain with a high diversity of surface forms. The influence of many ecological factors, especially hydrological regime, climate, phytogeographical phenomena and human activities, has brought about conditions conducive to the existence of rich biodiversity of plant and animal species and communities in the floodplain ecosystem (Zlinská 1999). Moreover, in some cases the destruction of biodiversity and functioning ecosystems can severely damage ecosystem services that support society and its long-term survival. Consequently, there should be more action to remedy this damage (Rybanič et al. 1999).

The Gabčíkovo-Nagymaros dam project is an example of how the issue of floodplain management can become extremely complex, in Slovakia and in Europe as a whole. This project resulted in an international conflict between Slovakia and Hungary that was solved at the International Court of Justice in the Hague. The main aim of the project was the improvement of flood protection for the area, improvement of river navigability and production of renewable energy by constructing the large dam, a hydroelectric power station, two navigation locks, a bypass canal, the Čunovo reservoir, and the intake structure at Dobrohošť. This construction had an enormous impact on ecological conditions in the Danube floodplains. There are hundreds of scientific works that describe the in-depth research and monitoring conducted to elucidate the effects of the ecological changes on particular taxonomic groups of plants and animals (e.g. Áč 1995, Mucha (ed.) 1999), as well as many proposals on how to improve the situation after the construction works were completed. The studies demonstrate that the ecosystem changes led to a decline in biological diversity (Bulánková 1995, Krno et al. 1999). Examples of this decline are often related to the increased spread of neophytic plants causing declines of natie species due to competition (Huba et al. 1998), the absence of strongly hydrophilous plants, and the impoverishment of the species inventory of most forest communities by 4 - 6 species (Uherčíková et al. 1999). On the other hand, Kirka (1999) stated that the reservoir is not as harmful as assumed. Besides other activities the reservoir fulfils an important role during extreme high discharges as a large refuge for drifted fish from the very long upper stretch of the river.

The Váh cascade brought several negative consequences to biodiversity, especially to fish. The problem has increased in the last number of years, to the extent that a petition was sent to the Slovak Minister of the Environment in 2011. The petition contained detailed descriptions of the extinctions of several fish populations and resulted in the prohibition of building of hydroelectric dams. The situation is similar for other large Slovak rivers (e.g. Hron, Nitra and Hornád). Hydropower energy and flood protection is strongly promoted by some stakeholders, biodiversity conservation by others.

The sustainable development of the Tisa river catchment was implemented (ICPDR 2011) as one of the last activities of the International Commission for the Protection of the Danube River and brought information related to biodiversity loss due to historic mistakes in floodplain management. As the most critical is the loss of large wetland areas as the result of change in land use management (ICPDR 2011).

Conclusions for Slovakia

Slovakia is a country with a very dense network of streams and rivers. They vary in terms of their length, size, flow, degree of naturalness, level and regulation intensity. Biodiversity associated with streams and appertained floodplains is enormous. There are thousands of taxa of vascular and non-vascular plants, vertebrates and invertebrates, hundreds of which are protected, and 15 NATURA 2000 habitats of European importance, three of which are priority habitats. There are also endemic Slovakian species associated with streams and floodplains. Land use change in Slovakia is mainly related to loss of agricultural and arable land types to forest. Direct systematic human interventions into the channels of major Slovak rivers date back to the 1770s, primarily in order to improve navigability and facilitate river transport. All rivers in Slovakia were affected by the regulation, to a minor or major extent. The main regulation activities involve removal of meanders, concreting of banks, and the construction of canals, artificial dams and hydropower stations. Inland water ecosystems and their protection is achieved through the implementation of the CBD and Ramsar Convention. Besides the National Biodiversity Strategy and its components related to ecosystem protection, Slovakia adopted a National Programme on wetlands (according to the Ramsar Convention) and a programme on restoration of river banks. An Integrated River Basin Management and Land Restoration Programme has also been implemented in Slovakia.

The biodiversity effects of multifunctional floodplain management in the country are various and they are visible at different levels. The first is the level of the protected floodplains with restricted management or management anchored in legislative acts. The evidence of biodiversity effects is well documented. The second is the level of small rivers and brooks outside protected areas with management within the local municipalities – the decisions at this level often do not consider biodiversity, and streams are regulated or polluted. The third level is the level of large rivers, especially the Danube, Morava and Váh. The best evidence of effects on biodiversity are available for the Danube floodplains, with hundreds of scientific articles and studies. The judgement of the International Court of Justice in The Hague also related not only to the Slovakia – Hungary conflict but also to biodiversity protection and multifunctional floodplain management. Conflicts among stakeholders in favour of hydropower production and dyke construction versus nature conservation are still ongoing.

Multifunctional floodplain management in Hungary

Rivers, floodplains, their biodiversity, and their regulation history

Hungary's most important river is the Danube (in Hungary 417 km, 817 000 km^2), which is Europe's second watercourse both in length and catchment area. Its largest tributary, the River Tisza, collects water from the Carpathians. Reaching the lowland areas of Hungary, both rivers slow down and become of middle section character. Meandering rivers developed wide floodplains with exceptionally diverse geomorphology, characterized especially by alluvial meadows and tall herb communities (EU Annex I habitats 6440 and 6430), open water surfaces, marshes, fens and reed beds. The Hungarian rivers are currently bordered by willow shrubs and alluvial forests (91E0). Other valuable habitats are the riparian mixed forests (91F0) and the characteristic standing water communities in the backwaters (Bölöni et al. 2008, Molnár et al. 2008).

The large landscape transformations influencing the present landscape started in Hungary in the late 18th century. Their main driving force was the increased European demand for cereals (Somogyi 2001). The tillage area could be increased most efficiently by reducing the floodplain area and draining the large lowland marshes and moorlands found in the Tisza basin. Traditional floodplain management had been abandoned and replaced by cereal production. For a more efficient transportation of crops rivers had been shortened, and dykes had been built. The majority of the floodways (i.e. the areas between the two dykes) remained under traditional smallholder use until the 1980s (e.g. crops, orchards pastures, meadows and vegetable gardens). By the end of the 20th century the smallholder use decreased gradually, which resulted in a rapid degradation of the semi-natural habitats. Since the collapse of the socialist agriculture, some regions along the Tisza are losing their human population as a consequence of serious economic and employment difficulties (Mihók et al. 2006, Balázs et al. 2009, Borsos et al. 2010). In the Danube valley demographic and economic indicators are more balanced, hosting many industrial establishments, power stations, urban areas, and the capital of Hungary. Despite all these pressures, three national parks have been established along the Danube, and nationally protected areas or Natura 2000 sites have relatively high extent (Beckmann and Jen 2004).

Wide-scale river regulations started in Hungary in 1846. Altogether 112 bends of the Tisza were cut through, and the river's length has been shortened by 457 km (37%) (Somogyi 2001). Dykes were built too close to the river, therefore floods have become more frequent and higher. Meanwhile the river's fall increased significantly, causing accelerated deepening of the river bed and, at high waters, the filling of the floodways with its own sediments. The length of the Danube has been shortened by 77 km, and 23 bends were cut through (Somogyi 2001). Outside the newly built dykes, especially in the Tisza basin, inland waters accumulated. To prevent this long-lasting inland water cover, the deep floodplains have been drained (length of draining channels is about 40 000 km), and pumps were established (Somogyi 2001). The drainage of inland waters caused water shortage at a landscape level, meanwhile increasing the number of catastrophic floods in the last decades (Somlyódi 2011). To solve the problems, multilateral dialogues started with the objective of transforming the current river management regime (Sendzimir et al. 2007, Werner et al. 2009, Borsos et al. 2010, Somlyódi 2011).

The loss of water had simultaneously ecological and social effects. The former shallow water surfaces, temporally inundated pastures and managed fishponds flooded by the Tisza were integral parts of the diverse and specified traditional land use system, causing extreme abundance of fish in the region. This system has been gradually cut back in the 16-17th centuries (during the Osman occupation), and ended totally with the construction of the dykes (Andrásfalvy 2007). The landscape change decimated not only the fish stocks but also the once famously rich avifauna: based on historical data, by the 20th century nesting of white pelicans (*Pelecanus onocrotalus*) and common cranes (*Grus grus*) ceased, and the numbers of ducks, geese, herons, pygmy cormorants (*Phalacrocorax pygmaeus*), great bustards (*Otis tarda*) and saker falcons (*Falco cherrug*) became markedly less (Ecsedi 2004). Grey wolves (*Canis lupus*) and golden jackals (*C. aureus*) have disappeared too from the lowland areas, possibly as a consequence of landscape transformations (Tóth et al. 2009, Heltai 2010). Significant increases in the number of alien fish, reptiles and molluscs started at the end of the 19th century, and nowadays is exceeding 40 species in the Danube (Puky et al. 2008, Bódis et al. 2012,). The proportion of alien species in the fish fauna in the larger rivers is 10-16% (Erős 2007). Floodplain meadows, tall herb communities and marshes shrank to a fraction of their original extent (approximately 80% of the former floodplains of the Tisza basin have been separated from the river). Meadows isolated from the floods transformed into arable land or dry short-grass steppe (Molnár and Borhidi, 2003). In the last decades habitat quality and regeneration potential of floodplain habitats is rapidly decreasing due to the expansion of invasive species and land abandonment (Botta-Dukát 2008, Molnár et al. 2008, Biró 2009).

River restoration projects, the role of multifunctionality in floodplain management and evidence for effects on biodiversity

The objectives of river and floodplain restoration projects in Hungary target in particular the reconstruction of grasslands on abandoned pastures, meadows and arable fields invaded by bastard indigo (*Amorpha fruticosa*) by grazing, mowing, grassland establishment, clearing of invasive trees and restoration of the water balance. In most projects, floodplain and habitat restoration has other functions beside biodiversity conservation (multifunctionality). Grassland management in most cases also provides **economic benefits** besides environmental ones, producing income from livestock production on restored grasslands, from hay, and the cut-off bastard indigo and alien tree species. The keeping of a traditional cattle breed, the Hungarian grey cattle, has also a gene preservation function in Hungary. In certain areas, the **social benefits** of multifunctional floodplain management are obvious. During the Tiszaalpár and Tiszatarján projects inhabitants have been involved in the management and clearing of the floodplain, by which jobs were created, fuel for winter was ensured, and in Tiszatarján, the heating of public institutional buildings was also realised. Information boards and educational trails in the restored areas serve also for **recreation** and environmental education. The renewal of traditional orchards representing integral parts of floodplain management was realized in the Mártély and Bökény projects. Traditional fishery management based on the natural dynamics of the river has been reconstructed by the local initiatives of two communes in the Nagykörű and Tiszabábolna projects. Revitalised wetland habitats and fishponds connected with bicycle routes on the Tisza dyke have become popular ecotourism destinations and excellent fishing sites as well. By reconstructing traditional landscape scenery and land use types, aesthetic and recreation functions were implemented in almost every project (Tiszatarján project: http://www.tiszatarjan.hu/wwf-egyuettmkoedes-tiszatarjanban).

Most recent floodplain management projects have as their main goal the suppression of invading bastard indigo and restoration of alluvial habitats. Abandoned pastures, meadows and arable fields, and invasive tree stands had been changed mostly into regenerating floodplain meadows and native woodlands. Extensive grazing helped grassland regeneration and decreased cover of bastard indigo in almost all cases. During most projects diverse landscape structure has recovered, and the quality and naturalness of habitats is continuously increasing. Effects on biodiversity were monitored usually by nature protection managers. However, systematic monitoring was implemented in only six of the 20 projects. In four cases monitoring was based on phytosociological or zoological relevés (Demény and Keresztessy 2007, Margóczi, Roboz 2011, Lájer ined., Tóth ined.). In two additional cases (Tiszaalpár and Nagykörű project) bird monitoring data are available. White-tailed Eagles (*Haliaeetus albicilla*) appeared in both areas and stood there constantly. Pygmy Cormorants (*Phalacrocorax pygmeus*), herons, shorebirds and ducks were nesting and gathering on the lakes. Glossy Ibis (*Plegadis falcinellus*), Black Stork (*Ciconia nigra*) and Whiskered Tern (*Chlidonias hybrid*) were observed on several occasions (Rimóczi ined., Bártol ined.) (Nagykörű project: http://www.elotiszaert.hu/bovebben.php?id=61 ; http://www.ild.eoldal.hu/cikkek/english.html).

During the restoration of grasslands the bastard indigo can be successfully suppressed with grazing or systematic mowing, but according to the experiences from several projects (Tiszatarján, Tiszabábolna, Álom-zug, Dunakömlőd), it cannot be eradicated. Grazing with Hungarian grey cattle proved to be the most successful method. A faster regeneration can be experienced after manual cut-offs of bastard indigo stands. In some of the ancient grasslands, stands of characteristic alluvial species became considerably stronger *(Orchis laxiflora* subsp. *laxiflora*, *Leucanthemella serotina, Clematis integrifolia, Peucedanum officinale, Iris spuria,* and the mushroom *Lepista nuda*). The long-lasting floods of 1999, 2000 and 2010, hindered regeneration considerably. The conversion of cropland and abandoned arable fields into grasslands (Tiszaalpár, Nagykörű, Mártély, Bökény, Álom-zug, Szarvas) had very different results. Regeneration was usually slow. In some cases disturbance-tolerant species or weeds became dominant, in other places generalist monocots like *Alopecurus pratensis, Poa trivialis, Bolboschoenus maritimus* or *Elymus repens* increased significantly. In some places rare annual floodplain species with high nature value appeared in large numbers (*Vicia biennis*, *Astragalus contortuplicatus*) *(*Tiszaalpár: http://knp.nemzetipark.gov.hu/index.php?pg=menu_1427, Mártély: http://knp.nemzetipark.gov.hu/index.php?pg=menu_1431).

During the wetland-restoration projects, floodplain marshes and lakes, tall herb communities and open water habitats have developed in place of dried-up wetlands or abandoned arable fields invaded by bastard indigo. In Nagykörű, the occurrence of 22 fish species (including two protected species, *Misgurnus fossilis* and *Rhodeus sericeus*) was recorded in the new traditionally managed fishpond. After the flood of 2006, the amount of young fish found in the lake was 20-30 young fish/m^3. In autumn more than 2000 well-developed pikes were released to the river, but the reproduction of invasive fish species still seems to be a problem (Demény and Keresztessy 2007). During the oxbow restorations in Tiszaalpár, Mártély, Bökény, and Gyügér-zug, river deposits were removed and floodgates were built. Increased water levels (30-40 cm) improved habitat quality and naturalness, some beaver families appeared, and diverse hydrophyte and wetland habitats developed. By the transformation of woods of non-native species and arable fields into native forests, young stands of *Populus canescens*, *P. nigra, P. alba, Fraxinus angustifolia* subsp. *pannonica, Quercus robur, Ulmus laevis* and *Salix alba* have been established in Tiszaalpár, Mártély, Bökény and Alsó-Szigetköz (Bökény: http://kmnp.nemzetipark.gov.hu/index.php?pg=menu_1136,Gyüger-zug: http://kmnp.nemzetipark.gov.hu/index.php?pg=menu_1120).

Conclusions for Hungary

Monofunctional floodplain management was focused on arable farming and non-native tree plantations. As a consequence of abandonment in the post-socialist period, the amount of bastard indigo increased, causing significant biodiversity loss especially in the floodplain meadows. Most MFM projects target rehabilitation of biodiversity by clearing bastard indigo, but additionally other economic, social and touristic functions were realised. Grazing with Hungarian grey cattle proved to be the most efficient method of bastard indigo management, and it also increased habitat quality and abundance of characteristic floodplain species. In the areas cleared of bastard indigo, natural grassland regeneration can be observed, but this was strongly hindered by the long-lasting floods of the years 1999, 2000 and 2010. Other MFM projects aim to restore the water balance of inner dyke wetlands. European beaver settled in some places, diversity of fish and avifauna increased, large numbers of migrating birds appeared, and nesting of some rare and protected birds has been observed.

Multifunctional floodplain management in the Ukraine

Rivers, floodplains, their biodiversity, and their regulation history

Superficial waters in Ukraine, except for the seaside areas, are presented mainly by the rivers, small amount of lakes along river valleys and artificial reservoirs (water basins and ponds) formed by the rivers. Ukraine has about 55,000 rivers, which include nine with catchment basins larger than 50,000 km^2 and 87 with catchment basins from 2,000 to 50,000 km^2. Total river length is over 220,000 km^2. There are more than 20,000 lakes. Of these, 43 have a surface of more than 10 km^2 (Gusieva, 2012). The basins of Dnieper, Southern Bug and Severski Donets lie mostly within Ukraine. The other large river basins are only partly inside Ukraine (Anonymous, 1991, Romanenko, 2004). The main part of the regulated runoff in Ukraine is concentrated in the Dnipropetrovsk storage reservoir cascade. There are 1,103 water storage reservoirs with a total storage capacity of 55.5 km^3 and additionally 48,000 ponds of 4.0 km^3 storage capacity in the Ukraine.

At present the large rivers, especially Dnieper, Severski Donets, Southern Bug, and their main tributaries are under constant anthropogenic influence. River floodplains are generally rich in biodiversity and host, for instance, 700 species of algae (Gerasimova, 2006), approximately 1000 species of vascular plants (Koreliakova, 1977, Baranovsky, 2000, Baranovxky and Aleksandrova, 2000), 250 species of zooplankton (Mykolaichuk, 2006), 200 species of zoobenthos (Zagubizhenko, 1999), 50 fish species (Kochet, 2010), and 250 bird species (Bulakhov et al, 2008). About 80% of the terrestrial vertebrate species of Ukraine inhabit ecosystems of water reservoirs or wetlands.

The total area of Ukraine is 603,700 km^2 (5.7% of the territory of Europe), which are currently inhabited by 45.6 million citizens. Despite immigration from eastern countries the Ukrainian population is decreasing continuously since 1993 (52.2 million) (Population, 2012). Population distribution is irregular through the country. More than 67% of people live in cities. Floodplains of rivers are quite populated in comparison with steppe or mountain areas. Land use in Ukraine is characterized by a high percentage of agricultural grounds (71.2%), tilled lands alone making up 53.8%. In particular, the Steppe zone is heavily used for agriculture (80%). A total of 15.6% of lands are covered by woods, 4.1% by artificial surfaces, and 1.6% of the territory is occupied by marshes. Water bodies of Ukraine occupy 24,169 km^2 (4.0% of the territory).

Inundated and flooded areas of Ukraine are characterised by a high diversity of physiographic conditions expressed by different microlandscapes, humidity, soil cover and vegetation types. In natural landscapes the water reservoirs of Steppe and Forest-Steppe of Ukraine are surrounded by forest ecosystems (Gensiruk, 1975; Nikolaenko, 1980). Long-term anthropogenic influence has led to loss and degeneration of forests that were substituted by meadows, pastures and from the second part of the 20th century by tillage. That replacement caused mud accumulation and overgrowing of ponds with aero-aquatic plants.

Anthropogenic influence on the rivers is expressed mainly as a realisation of hydro-engineering projects including the creation of dams and the accumulation of water in ponds (for using all year round) and water basins for energy production, water supply, navigation and recreation purposes. Other hydro-engineering projects (construction of dams, channels, etc.) are connected with the management of water reservoirs (Bogoslovsky, 1974). Much ploughing of river valley slopes and floodplains resulted in silting and clogging of riverbeds. Subsequent reduction of floodplain drainage caused a raising of subsoil waters that involves flooding of river valleys, hydrology and hydrochemistry change, silting and excessive overgrowing of riverbeds and inundated ponds (Baranovsky, Demianov, Grynjuk, 2001). Despite the overgrowing the plant diversity decreased and entailed the loss of diversity of associated animal species.

Small rivers changed to the greatest extent: increased sedimentation, and development of reeds (*Phragmities australis (Cav.) Trin. ex Steud)* transformed a natural community into a simpler and depauperate one.

The river regulation history in Ukraine was initiated in 1927, when the construction of Dniprovska hydropower station began. In 1930-1980 the main objective of the national economy was the river super-regulation for water engineering and land improvement. The most anthropogenic transformation is presented by water reservoirs and ponds. The ecosystems of the rivers and their valleys changed considerably: meadows, woods and arable lands were flooded, hydrology and hydrochemistry altered, the soils were impounded, and the vegetation changed. Eventually it led to a decrease of biological diversity. The steppe zone of Ukraine has undergone pronounced anthropogenic change to such a degree that it led to basic changes in ecosystems of almost all floodplains until the end of the 20th century.

At the Dnieper, the water basin of the Dniprovska Hydroelectric Power Station was finished in 1935. In 1950–1975 five more water reservoirs were created (Kyivske, Kanivske, Kremenchugske, Dniprodzerzhinske and Kakhovske) and the Dnieper flow became completely regulated (Hydrology, 1981). The distinctive feature of the Southern Bug is the intensive regulation of flow by 197 water basins and almost 7000 ponds with a total volume of 1.5 km^3, created in the 1950s for the purpose of hydroelectric power generation. Nowadays most of these hydroelectric stations have become ruins and only six medium and several small hydroelectric units are still working. The riverbed of the Ukrainian part of Seversky Donets is dammed three times. The downstream reach has seven sluices located in the Russian Federation, six of which were built in 1911–1914. Many tributaries also have many dams; eight are located near Kharkiv, with more than ten around Sloviansk.

In river basins of the middle-sized rivers of the Ukraine some small water reservoirs and many ponds were constructed since the 1960s: from several dozens along some rivers to 1865 storage pools on the Ros River (Vyshnevsky et al., 2011). The incessant destruction of small rivers became one of the biggest regional environmental problems (Baranovsky et al., 2001). The Dnieper catchment area alone has 20,500 rivers with a total length of over 105,000 km. The small rivers are especially important and form 60% of the water resources of Ukraine. The ecological conditions of the majority of the small rivers of the Dnieper basin are qualified either as catastrophic or as bad (Yatsyk et al., 2007). The Bokovenka river is strongly regulated all the way along: the river is only 59 km long, but has 10 ponds (at the upper reach and middle course) and two water reservoirs (at the lower reach). In many respects the high extent of flow regulation is connected to the high number of settlements located along the river valley (Zagubizhenko et al., 2002).

The modern state of the rivers is determined by the long-term anthropogenic influence both on the catchment areas and on the river valleys. At present, restoration of the natural hydrological conditions of the rivers is of paramount importance. It should entail restoration of natural conditions of ecosystems and, finally, biodiversity.

The main effect of river regulation is that huge areas of floodplain became permanently flooded and were thus lost as habitat for floodplain specialist species. Creation of water reservoirs on the large rivers resulted in flooding of large areas of floodplain and, sometimes, of the second terraces of river valleys that were turned into sink lakes (Avakjan & Sharapov, 1968; Vendrov 1970). The total area of the Dnieper's six large reservoirs at the flood-control storage level is 6880 km^2. Only the two largest water basins – Kremenchugske and Kahovske – permanently flooded about 4000 km^2 of the Dnieper valley (Vyshnevsky et al., 2011).

The landflood resulted not only in total destruction of natural vegetation and ecosystems of floodplains, but also in the occurrence of large areas of impoundments having quite weak current. For 3-4 months, 80-90% of the Dnieper water area blooms and biomass of cyanobacteria averages about 60-100 g/m^3, that is, 70-90% of the total biomass of phytoplankton (Yatsyk et al., 2007). The areas closed to the reservoirs are barren wetlands, which are frequently protected by dams. For the Dnieper floodplain, the areas protected by dams from flooding average 2450 km^2 (Vyshnevskyi et al., 2011). All of that greatly reduced the initial high level of biodiversity of large river floodplains in the past (Akinfiev, 1889).

The flow regulation of the middle rivers leads to permanent flooding of bottomland and to disturbance of their hydrological regime. Human intervention does not keep the high water level in times of flood for security reasons to protect the hydropower dams from destruction. The absence of high water changed the regime that had existed for millennia, and thereby reduced the removal of excessive organic matter from inundated reservoirs and diminished the beneficial natural fertilization of the floodplain soil by floods. As a result, natural floodplain ecosystems died gradually. Those processes are accompanied by a noticeable decrease in biodiversity of both reservoirs and adjacent lands (Akinfiev, 1889, Baranovsky, 2002, Baranovsky and Aleksandrova, 2005).

Regulation of the small rivers (construction of ponds) has the same result but mostly appeared as a reduction in riverbed flushing in spring. In conjunction with the ploughing of land in river valleys it leads to inevitable silting and overgrowing. Moreover, the drainage reduction causes a raising of subsoil waters that promotes underflooding of the river valleys. Naturally diverse woodland ecosystems of floodplains (Belgard, 1950) change into simple communities with reduced biodiversity.

River restoration projects, the role of multifunctionality in floodplain management and evidence for effects on biodiversity

Long-term (about 40 years) research of plant diversity of rivers of the Dnieper and Southern Bug basins allowed the development of a set of measures for restoration of natural conditions and biodiversity of the river floodplains of a Steppe zone (Baranovsky, 2000, Loza et al, 2004, Baranovsky, 2005, Baranovsky, Zagubizhenko, Mykolaichuk, 2007). Long-term cooperation of scientists with basin authorities and waterworks allowed restoration projects to be designed, which were realised in the Dnieper basin.

The projects included the following points:

- retrospective analysis of the river state (hydrology, biodiversity, etc.);
- preliminary study of biodiversity of a floodplain;
- hydro-engineering (dredging) works carried out under the control of ecology experts (no river-channel straightening allowed) with preservation of the areas with especially valuable flora and fauna;
- newly formed coastal slopes should be covered with meadow grasses;
- forest shelter belts should be planted along river banks.

To restore the hydrological regime of river and floodplain ecosystems the projects include a retrospective analysis of the river’s state and an assessment of the anthropogenic transformation rate of the ecosystems with the help of analysis of biodiversity and ecosystem structure alterations (Baranovsky, 2009). The main measure of hydrological regime restoration was the hydro-mechanical clearing of a channel. After clearing the river, bank slopes were formed.

The next step was the biological protection of river banks by greening and revegetation. This approach is based on the massive root systems of trees, bushes and grass that strengthen soil, enhance sustainability and prevent soil erosion. Natural revegetation of the bank slopes and riverside ecosystems of a floodplain is put into effect very slowly at the expense of weed invasion and increased levels of soil erosion occur during the early years. It may bring the clearing of a river channel to naught. So, riverside shelter belts should be an urgent measure against soil erosion (Baranovsky et al., 2009).

The other benefit of afforestation is the forming of a shadow structure that hampers the renewal of aero-aquatic plants such as reeds (Baranovsky et al., 2009). The forest's shadow decreases evaporation and water heating, and improves the sanitary state of a water reservoir as a consequence. Moreover, floodplain forests have a high water regulation ability (Tkachenko, 1975) and form a microclimate that promotes an increase in biodiversity (Grytsan, 2000; Kulik et al, 2008). Afforestation provides additional benefits for biodiversity because the selected species for planting should form a sustainable ecosystem with diverse communities of plants, animals and fungi.

Dnipropetrovsk National University and the State Regional Planning and Survey Institute "Dniprogiprovodhoz" started complex multifunctional projects on environmental rehabilitation and biodiversity restoration of rivers about 10 years ago. One of the examples of such works is the project *Restoration of a hydrological regimen of the wetland Diovsky plavni*. The project cleared channels of impounded floodplains of the right bank of Dnieper River above Dnipropetrovsk (the upper part of the Dniprovske water reservoir). The project was carried out according to the stages described above. As a result of the project, an increase in biodiversity was noted in the water bodies and the floodplain (Grytsan et al., 2006) during the first period, mainly for plants. Another example is the project 'Restoration of a hydrological regime of the Orel River' at the border of Dnipropetrovsk and Poltava provinces. Riverside forest shelter belts of white willow (*Salix alba* L.) were created. The subsequent increase in plant diversity on the floodplain was confirmed (Baranovsky et al., 2009).

The main purpose of the mentioned projects was to decrease the ground water level of the adjacent populated and agriculture lands. While this largely economic aim was realised, the rehabilitation of ecosystems and biodiversity was effectively realised as well. Successful small multifunctional projects of the Dniester floodplain rehabilitation are reported by Rusev and Ruseva (2000). The projects included clearance of small sections of the river bed, making small gaps in the dykes with subsequent renewal of flowage between water bodies, reclamation of the riverside slopes and plantations of trees. The result was restoration of hydrological regime, revitalisation of the floodplain's meadows and increases in biodiversity and population abundance. The populations of fish, geese, herons, glossy ibises, ducks and waders increased (Rusev, 2003).

Conclusions for the Ukraine

The modern state of floodplains in Ukraine is determined by long-term anthropogenic influence. Changing of the floodplains may be divided into a number of stages: 1) destruction of wood vegetation in river valleys; 2) ploughing of the catchment areas; 3) overgrazing; 4) dumping and creation of artificial reservoirs, irrigation and drainage construction; 5) ploughing of the floodplains. It finally leads to submergence and impoundment of lands, change of hydrology and hydrochemistry of the water bodies, and a decrease in biodiversity.

The implementation of science-based management actions may improve the floodplains and restore lost biodiversity. Examples of such relatively successful measures on the conservation of biodiversity in floodplains are few in Ukraine. Multifunctionality as sustainable management of floodplains receives little attention from policy makers and authorities in Ukraine. There is much scientific literature on floodplain management and biodiversity. Unfortunately most such research is not related as management is described in some papers and biodiversity in others, while research assessing the biodiversity effects of management interventions is mostly lacking.

• Summary, conclusions and recommendations

There is seemingly no alternative to multifunctional approaches in future floodplain management. Integration of all existing uses and demands is essential. In order to make efficient use of the management resources as well as the ecosystem services, win-win-situations need to be achieved and biodiversity has to play a crucial role. Multifunctional use of floodplains is a central theme some countries such as the Netherlands, Ireland and Hungary and management of floodplains goes hand in hand with sustainable economic activities such as development of ecotourism, mineral extraction, and other, resulting in flood safety and increased biodiversity. As a result, the biodiversity is increasing, for several areas, e.g. in the Netherlands.

Multifunctional only shows success where stakeholders with diverse expertise and interests are involved in all stages of planning and implementation of regarding projects. It is recognized that such participatory processes are beneficial for environmental resource management (EC 2005; Paavola et al. 2009; Silva et al. 2009), but efficient mechanisms are lacking and a big gap remains between the rhetoric on participation and the real-life implementation on participatory processes (Rauschmayer et al. 2009).

Administrative structures often support the subsequent standstill an all levels: The sectoral organization of national governmental structures has its analogy in the organization of the European Administration and the European policies are not fostering multifunctionality. The importance of the Water Framework Directive for floodplain management can hardly be underestimated, since no other strategy else has triggered so many waterbody related measures. But, the Water Framework Directive focuses largely on ecological improvements, which is not a multifunctional approach. Even though in its implementation the scope has broadened quite a bit and positive side effects do touch other sectors as well, future amendments of the directive should be used to further broaden its scope and install multifunctionality in this successful program. Concerning other EU directives, the Habitat Directive similarly targets the safeguarding of natural values and conservation issues and lacks a multifunctional background. This could only be changed by opening its focus as mentioned in the previous paragraph for the WFD.

When comparing the situation in the investigated countries, an interesting pattern of regional differences in management goals and approaches occurs (Table 3). Whereas flood protection is the top priority in floodplain management in the Netherland, Ireland, and Hungary, the focus is set on navigation in Germany, while Slovakia and Ukraine seem to have a more mixed agenda. Multifunctional flood plain management seems to be possible under all three strategies but is showing differences in size and number of projects, which is mainly due to different levels of responsibility for water management in the countries, ranging from centralized national responsibility in the Netherlands and Hungary to region provincial governance in Germany and Ireland and a rather mixed situation in Slovakia and the Ukraine. Regarding the management approaches, there is a compelling common set of measures all over Europe, targeting not only the restoration of hydrological connectivity at different scales, but also the adaptation and extensification of land use in flood plains as a precautionary principle. Biodiversity may benefit from all these interventions but evidence is rare as only few projects have documented the respective impacts and responses.

Table 3. Floodplains, floodplain management approaches, and evidence for biodiversity impact in the six investigated European countries.

Biophysical conditions	
IE	Many small river systems throughout the country; a number of large rivers with extensive floodplains
NL	"The Dutch live in a river delta"
DE	All kinds of rivers and floodplains from alpine to lowland, from pristine streams to heavily modified waterbodies but mainly dominated by large river systems with formerly extensive floodplains
AT	Dense river network of alpine until lowland river stretches
SK	Dense network of streams including mountain brooks, upland small rivers and mighty rivers in lowlands; average density of river network is 1.1 km/km^2
HU	Meandering rivers in a flat landscape
UA	Most rivers are regulated and transformed into reservoir systems
Main land uses in floodplain	
IE	Hydropower, agriculture, housing, tourism and leisure
NL	Most land is farmland, secondary functions are nature conservation and recreation
DE	Agriculture, forestry, settlements and industry
AT	Hydropower, agriculture, settlements and industry, natural remnants
SK	Hydropower, settlements, agriculture and industry, nature protection, recreation and tourism
HU	Agriculture, forestry, nature conservation
UA	Hydropower, agriculture, settlements and industry, recreation, quasi-natural remnants
Governance level responsible for floodplain management	
IE	Combination of central (e.g. hydropower) and local/regional (e.g. agriculture, housing)
NL	Centralized, decisions are taken at national and regional levels. However land users do influence local (micro-level) development
DE	Regional responsibilities but often depending on national framework
AT	Local and regional responsibilities
SK	Case dependent, mostly local, but by the big rivers regional till governmental
HU	Centralized, but involvement of regional and local stakeholders
UA	Central and regional, but not lower than the province level
Main strategic approaches / management aims	
IE	Emphasis is currently on flood alleviation and drainage; some priority given to facilitation of fish movement
NL	Flood protection is top priority, and overriding other sectors with regard to planning and land use. The Ministry for Water and Infrastructure has a key role in the floodplain areas.
DE	Navigation along big rivers most important, flood protection also high priority, recently (mainly local or regional) efforts to combine the two with floodplain restoration and biodiversity
AT	Conservation of last free-running river sections and increase of retention area in upper courses
SK	Decrease of water pollution, conservation of nature close floodplains (incl. 12 Ramsar sites), flood protection, revitalisation
HU	Flood protection is the top priority, forestry is the second

UA Developed legislation of river conservation, but weak legal enforcement

Multifunctional management approaches

IE Weir construction that allows both water flow control and passage of aquatic species; provision of habitat for species of conservation concern; engagement with key stakeholders, e.g. fisheries, farmers and local communities

NL Management is multifunctional, with particular interest for flood protection, nature conservation and tourism. However, flood protection is overriding all other interests

DE Some efforts to restrict and extensify agricultural use, nationwide program for restoring hydrological connectivity on big navigable rivers, local and regional but still limited activities for dike relocation, restoration and biodiversity conservation to foster synergies and win-wins between the different uses

AT Danube: restoring hydrological connectivity considering conservation, navigation and recreation

SK Danube and Váh – creation of multimodal transport corridors respecting nature values and offering possibility for tourism

HU Multifunctional project dealing with reintroduction of grazing, fighting against invasive species and hydrological rehabilitation

UA Drainage or irrigation are primary aims, biodiversity conservation may be concomitant

Evidence for biodiversity impact

IE Negative effects recorded on Atlantic salmon and freshwater pearl mussel (because of disturbance/activities on floodplains) and on corncrake due to habitat flooding and changes in farming practices

NL Many projects are still in the implementation phase, but some projects have been ongoing for 20 years and show positive impacts regarding biodiversity, in particular due to increased natural dynamics and increased habitat diversity. As a result, rare and protected species have returned.

DE Too few studies and lack of effective monitoring but a tendency towards positive impacts upon species as well as habitat, even water balance with a positive tendency

AT Evidence from lateral reconnection in Danube NP: rheophile specialists increase

SK Rich evidence mainly from Gabčíkovo and the Váh cascade including whole spectrum of both aquatic and terrestrial groups of taxa

HU Bird and fish diversity increased, plant diversity could be conserved

UA Restoration of natural hydrological regimen resulted in biodiversity increase

Summarizing, we can state, that multifunctional flood plain management has become an issue of growing attention in several European countries but due to differences in management strategies and governance it is still a complex and underresearched topic especially regarding its impact on biodiversity.

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Annexes 6.3.1 – ANNEX 1

De Blauwe Kamer

www.rijninbeeld.nl depoldering

picture: www.rijninbeeld.nl

River branch	Neder-Rijn (Lower Rhine)
Province	Utrecht / Gelderland
Community	Rhenen
Start nature development	1984 procurement, 1992 design
Owner / manager	UtrechtsLandschap
Area	120 ha
Accessibility	partially accessible on the paths, partially closed
Measures	• lowering the embankment in two places, • construction of a side channel, • heightening the ground level of the meadow, • construction of an isolated shallow swamp, • construction of an inland drainage system

Species group	Before nature restoration		After nature restoration		Evaluation development
	Number of (rare) species	Number of Red List species	Number of (rare) species	Number of Red List species	
Flora*	48-54	22-23	50-66	23-25	
Breeding birds*	36	?	max 75	max 20	
Dragonflies*	17-20	1	35	4	
Butterflies*	24	3	24-27	2-3	
Grasshoppers*	12	1	14	1	
Other species	Beaver, grass snake, Natterjack toad *(Epidaleacalamita)*				
* = all species					

Duursche Waarden depoldering
www.rijninbeeld.nl

picture: www.synbiosys.alterra.nl

River branch	IJssel
Province	Overijssel
Community:	Olst-Wijhe
Start nature restoration	1987 floodplain meadow (grazed), 1989 design
Owner / manager	Staatsbosbeheer
Area:	150 ha (70 ha grazed)
Accessibility	partially accessible
Measures	• The construction of a downstream connected channel in 1989; • Part of the sand lake is filled in, part of a floodplain meadow was raised; • Construction of an observation hut from the dyke on the northern side of the ditches (1989); and of an observation tower at the brick factory; • The extension of the ditches in 2006 on the south-west side of the territory (third lob); • The construction of a natural border on the north side of the territory in 2005, by removing the hard riverbank substrate and part of the top layer, a sandy border remains, groynes stayed and there is a construction to restrict access by boats.

Results	Before nature restoration		After nature restoration		Evaluation development
Species group	Number of (rare) species	Number of Red List species	Number of (rare) species	Number of Red List species	
Flora*	12-14	7	29	11	
Breeding birds*	31	12	+/-35	11	
Dragonflies*	?	?	27-29	5	
Butterflies*	19	0	29	4	
Grasshoppers*	12	1	13	1	
Fish*	?	?	20	4	
Amphibians*	6	2	4	0	

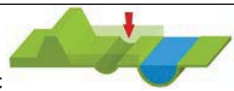
* = all species

LeeuwenseWaard excavation of the floodplain topsoil
www.rijninbeeld.nl

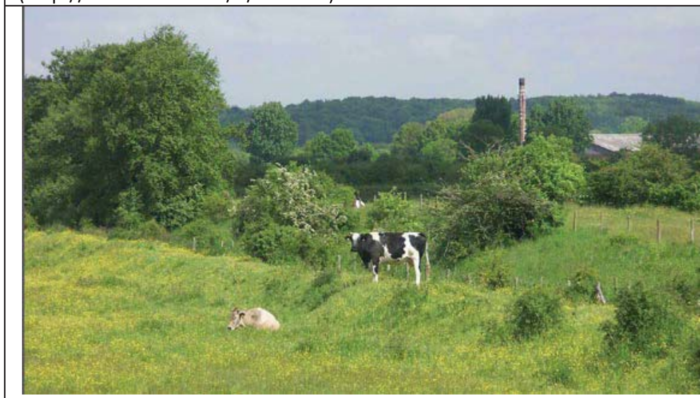
Picture of the Leeuwensche Waard (www.rijninbeeld.nl)

River branch	Waal
Province	Gelderland
Community:	Druten
Start nature development	1994
Owner / manager	Dekker van de Kamp
Area:	About 115 ha (sand lake included)
Accessibility	partially free accessible (western part), the eastern part is closed
Measures	• End of 2003: first phase filling up the Kaliwaal; • 2003: north eastern side a temporary quay is constructed; • 2003: Lowering a large part of the space between the shore and the summer dyke; • 2008: Realisation of a large oxbow around the Kaliwaal; • 2008: Elongating the quay along the south side of the Kaliwaal to the Leeuwense Waard; • 2008: Construction of a new quay on the dyke side of the oxbow

Species group	Before nature restoration		After nature restoration		Evaluation development
	Number of (rare) species	Number of Red List species	Number of (rare) species	Number of Red List species	
Flora*	18	5	32-41	10	
Breeding birds*					
Dragon flies*	18	0	18	2	
Butterflies*			17	1	
Grasshoppers*	7	0	10-11	1	
Other species					
* = all species					

Oeffeltermeent  Excavation of the floodplain top soil
(http://maasinbeeld.nl/2/?cat=36)

 Relocation of the dyke



River branch	Meuse
Province	Noord-Brabant
Community:	Boxmeer
Start nature restoration	1982 floodplain meadow (grazed), 1989 design
Owner / manager	State Forestry Service/Gravel exploitation companies
Area:	100 ha (most grazed)
Accessibility	accessible on public footpaths
Measures	• Construction of a summer dyke, to avoid flooding of rare and valuable floodplain meadows (early 80s) • Excavation of livestock ponds as part of nature restoration (early 90s); • Removal top soil to restore ruderal conditions in part of the area (1991); • Reconstruction and strengthening of river dyke.

Results

Species group	Before nature restoration		After nature restoration		Evaluation development
	Number of (rare) species	Number of Red List species	Number of (rare) species	Number of Red List species	
Flora*	41	26	36	20	
Breeding birds	22	12	22	9	
Dragonflies*	?	?	15	2	
Butterflies*	?	?	23	2	
Grasshoppers*	?	?	8	0	
Fish					
Herpetofauna		0	6	2	
* = all species					

Process parameter	**change**
Natural development	
Hydro-morphodynamics	
Natural grazing	
Seepage	

Pilot project Meers
http://www.maasinbeeld.nl/publicaties/ProefprojectMeers.pdf
(Peters et al. 2007)

River branch	Meuse
Province	Limburg
Community:	Stein
Start nature restoration	1998
Owner / manager	Natuurmonumenten (NGO), mineral extraction company
Area:	53 ha (grazed)
Accessibility	accessible
Measures	• Widening riverbed over 200m, lowering river bank • (Partly) Filling in deep gravel pit (lake) • Landscaping of the gravel pits • Establishment recreation facilities • Establishing one grazed management unit • Construction shallow gravel channel along river

Results

Species group	Before nature restoration		After nature restoration		Evaluation development
	Number of (rare) species	Number of Red List species	Number of (rare) species	Number of Red List species	
Flora*	28	12	57	30	
Breeding birds	13-15	8-11	13-17	8-10	
Dragonflies*	?*	0	22*	2	
Butterflies*	10*	1	15*	3	
Bats*	?	?	3*	3	
Other species					Beaver, Blue-winged grasshopper
Fish					Many important rheophile fish species returned

Process parameter	**change**
Natural development	
Hydro-morphodynamics	
Natural grazing	
Other processes	

Annex C.3 - Expert assessment on the effects of floodplain management interventions on the provision of ecosystem services

(cf. Chapter 6.3.3)

Multifunctionality of floodplain management: a matrix relating interventions to ecosystem services

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Abstract

One important approach to obtaining multiple ESS in the same area is the concept of green infrastructure (GI) that was recently strongly taken up by the European Commission. Multifunctionality is a key feature of GI which is defined as an "interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations. Floodplains of large European lowland rivers are landscapes where the need for the provision of multiple ecosystem services is particularly high. In this work we provide an overview of the impact of floodplain interventions on the provision of ecosystem services (ESS). By means of an expert consultation, we defined a set 38 relevant floodplain management interventions, assessed the effects of these interventions on 21 relevant ecosystem services and evaluated the impact of the intervention on the multifunctionality of the floodplain by calculating an index that summarizes the positive and negative effects on the provision of the different ESS. This multifunctionality index quantified the overall impact on all considered ESS ranging from -1 (negative impact on all ESS) to +1 (positive impact on all ESS). Interventions related to restauration and rehabilitation increased strongly the multifunctionality of the landscape and caused win-win situations for enhancing overall ESS provision, but also all three ESS-sectors (production, regulation and maintenance, and culture). Conventional regulation but also interventions related to extraction, infrastructure and intensive land use caused lose-lose situations with decrease in multifunctionality and negative effects for the provision of all three sectors of ESS. The approach is based on expertise from researchers and practitioners of several European countries, and should be useful to provide an overview for decision makers at multiple governance levels. Further research should include the development of widely applicable indicators for the ecosystem services and generate long-term data sets to monitor effects on ESS provision in European floodplain landscapes.

Keywords: floodplain management, green infrastructure, nature conservation, multifunctionality index, hydrological engineering, restauration, recreation

Introduction

Over the last few decades the demand for natural resources has grown worldwide due to increasing human population size, exponential economic growth and global consumption resulting in an expansion of human settlements and infrastructures, fragmentation and degradation of natural landscapes and an alarming loss of biodiversity and ecosystem services (ESS) (Cardinale et al. 2012, MEA 2005). ESS are arising from living organisms (biota) or the interaction of biotic and abiotic processes, and refer specifically to the 'final' outputs from ecological systems that are providing benefits to humans (Haines-Young et al. 2013, Maes et al. 2013). The society tends to value (in a monetary or non-monetary way) the potential benefits that a landscape might provide and adjust management practices towards desiderate outputs by maximising the benefits gained from one or some of the services (such as the provision of goods) leading to loss of multifunctionality and to degradation of natural capital at the expense of human welfare (TEEB 2010). In this sense, mono- or multifunctionality is not an attribute of an ecosystem *per se* but rather a result of the interaction between ecosystem, society and applied value system (Haines-Young and Potschin 2004). Changing the value system has the potential to improve the multi-functional use of the landscape. For example, in the past biodiversity has been often conserved only for its intrinsic value neglecting its major role in securing the provision of ecosystem services. As a result, the opportunity costs of conservation have been perceived as too high (Balvanera et al. 2001). The recognition of biodiversity as a major direct and indirect source of ecosystem service provision is a relatively new development. The relationship of both is seen as multi-layered since biodiversity might regulate ecosystem processes as well as provide final ecosystem services and/or goods (Mace et al. 2012). The economic value of ecosystem services and biodiversity reached recently increased recognition and is suggested to be factored into decision making processes and accounting systems (TEEB 2010). This development is reflected in the Biodiversity Strategy of the European Union (EU) to 2020 (COM 244 2011) which recognizes the significant economic value of biodiversity and the services it provides and sets out a headline target for halting "the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, and restoring them in so far as feasible". The headline target is supported by six further targets. One of the six supporting targets - target 2 - demands that "by 2020, ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15 % of degraded ecosystems" and is supported - among others - by

Action 5 which demands the mapping and assessment of the state of ecosystems and their services by 2014, and the assessment of the economic value of such services aiming to improve the knowledge of ESS and their sustainable use as underpinning element of human economies (COM 244 2011, Maes et al. 2013). In the short-term, the essential challenge of Action 5 under the EU Biodiversity Strategy is to gather and to operationalize the information and scientific knowledge currently available on ecosystems and their services across Europe (Maes et al. 2013). The integration of ESS into accounting and reporting systems at EU and national levels is expected to be completed by 2020 (COM 244 2011), and the importance of investing in natural ecosystems, in particular urban green areas, floodplains and nature for recreation, as a source of economic development is recognized in the EU's regional and cohesion policy (COM 17 2011).

One important approach to obtaining multiple ESS in the same area is the concept of green infrastructure (GI) that was mainly developed in the USA (Benedict 2000, McMahon 2000), and is recently strongly taken up by the European Commission by linking it with policies on e.g. adaptation to climate change (COM 147 2009), cohesion (COM 17 2011) as well as with biodiversity and ESS (COM 244 2011). Multifunctionality is a key feature of GI which is defined as an "interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations" (Benedict and McMahon 2002). Floodplains of large lowland rivers are landscapes where the need for the provision of multiple ecosystem services is particularly high (Scholz et al. 2012). Provision of freshwater, products from agriculture, fishery and forestry, hydro- power, as well as bioremediation, flood protection, habitat and gene pool protection, and recreation opportunities might be the most commonly required ESS, but priorities differ strongly among European countries (Schindler et al. in prep.). Located in agricultural and urbanized landscape matrix, floodplain present natural remnants of high value for conservation relevant species, ecotourism and recreation, and are at the same time under high human land use pressure (Scholz et al. 2012).

Since the Millennium Ecosystem Assessment (MEA 2005) an exponential growth has taken place in publications on assessing, quantifying and mapping ESS (Hermann et al. 2011, Seppelt et al. 2012, Crossman et al. 2013). Recent papers are dealing with the relation of land cover and ESS (Burkhardt et al. 2009, 2012, Koschke et al. 2012, Hermann et al. 2013), biodiversity and ESS (Cardinale et al. 2012, Mace et al. 2012), and trade-offs among ESS (Kandziora et al. 2013), but the effects of different human management actions on the provision of ESS has rarely been assessed (Richter and Thomas 2007). It is assumed that direct human interventions in natural capital are most responsible for changes in ESS provision. In this paper we are using floodplains as a demonstration case to assess the impact of management interventions on the multifunctionality of the landscape by using the expected impact of those interventions on a wide range of ecosystem services as a proxy for multifunctionality. In this sense, the paper aims to identify management options which would support reaching the targets set by the Biodiversity Strategy (COM 244 2011). In detail, we conducted an expert consultation on multifunctional floodplain management in temperate Europe aiming at (i) defining a set of most relevant floodplain management interventions, (ii) assessing the effects of these interventions on all relevant ecosystem services and (iii) evaluating the impact of the intervention on the multifunctionality of the floodplain by calculating an index that summarizes the positive and negative effects on the provision of the different ESS.

Methods:

Study approach:

In this research rivers and their floodplains were considered a functional unit. We focussed on floodplains of large rivers in temperate Europe such as the Danube, Dnieper, Rhine, Tisza, Meuse, Oder. Knowledge synthesis was done by expert consultations, experts were consulted via a network of knowledge approach (Balian et al. 2012). As a first step, an expert workshop was convened with 16 selected experts. Subsequent tasks were organized and conducted by teleconferences. Participating experts were from the Netherlands, Germany, Austria, Slovakia, Hungary, and the Ukraine, and had partly also strong expertise in respect to other countries. They had a diverse scientific and institutional background as researchers, practitioners and policy makers.

Bundles of interventions:

As an outcome of the expert consultation workshop, 38 different floodplain interventions considered typical for these floodplains were considered in the assessment. The interventions included for instance change of land use intensity, removal of river bank fixation, elongation of river length, creation a new water courses and multiple channels, and re-connection of backwaters (Lorenz et al. 2012). The interventions were defined as a group of specific measures with similar aims and similar consequences in terms of expected ESS supply and demand (cf. Burkhardt et al. 2012). The 38 interventions were grouped into the following nine bundles (Table 1): 1: ‘production-extraction’, 2: ‘production-infrastructure’, 3: ‘production-intensive land use’, 4: ‘production-extensive land use’, 5: ‘hydrological engineering-regulation’, 6: ‘hydrological engineering-rehabilitation’, 7: ‘restauration-connectivity’, 8: ‘restauration-renaturation’, 9: recreation.

ESS classification:

We applied the Common International Classification of Ecosystem Services (CICES), which is currently under development sponsored by the European Environment Agency, as part of its input to the revision of the System of Economic and Environmental Accounting led by the United Nations Statistical Division (UNSD). CICES has been proposed to be used for ecosystem assessments and valuation in the frame of the Biodiversity Strategy in Europe by the Working Group on Mapping and Assessment on Ecosystems and their Services (MAES) (Maes et al. 2013). In this classification special care was taken to avoid double counting (i.e. considering a service provided by nature under two or more ecosystem service categories) and therefore it is particularly suitable, when aiming at summarizing the different ESS. We used 21 ESS for our assessment (Table 2) and only ignored one of the CICES-classification that is dealing with marine plants and animals for food.

Table 1. Nine bundles of interventions, 38 intervetions and specific measures included in this assessment

Bundle of interventions	Intervention	Examples for specific measures and comments
1) Production – extraction		
	Surface water extraction	e.g. from the river; e.g. for industries, power plants, human consumption, navigation, agriculture, aquaculture
	Groundwater extraction	e.g. for industries, power plants, human consumption, navigation, agriculture, aquaculture; incl. establishing pumping wells, establishing of water protection zones
	Mineral resource extraction	clay, sand and gravel extraction
2) Production – infrastructure		
	Terrestrial settlement and traffic infrastructure [except dikes, etc.]	construction, maintenance and usage of houses, industries, commercial areas; traffic infrastructure, incl. urban sprawl (planned or unplanned)
	Energy conversion	mainly hydropower (including cooling water release)
	Navigational infrastructure	navigation, improving navigability of the river, river bed excavation, establishment of groynes, construction of dams and locks [but not dikes]
3) Production – intensive land use		
	Forestry intensive	forest plantations (including monocultures of native or non-native spp.), monofunctional forestry, including forestry for biomass production
	Agriculture intensive	incl. intensive grassland, including crops for bioenegry and biomass production
	Fishery intensive	extraction of relatively big amount of fish from ecosystem, fish-stocking, creation of fish ponds
4) Production – extensive land use		
	Forestry extensive	enabling spontaneous forest development (sustainable timber harvesting without any strong intervention)
	Agriculture extensive	incl. multiple uses, small scale grazing, low lifestock units per area
	Fishery extensive	placement of spawning gravel, small-scale hobby fishing
	Hunting	game management
5) Hydrological engineering – regulation		
	channel corrections	straightening, meander-cut off
	dike construction	building new, reinforce existing dikes
	bank/bed stabilization	riprap, bed enforcement
	sediment removal/dredging	incl. non-navigable rivers; including temporal opening of a dam
	detention basins	in upper or lower courses [facilities for the retention of stromwater, construction in "average" floodplain, i.e. might be partly natural, partly rather intensively used]
	controlled retention areas	e.g. "controlled polders", entrance and release of water is controlled by constructions
6) Hydrological engineering – rehabilitation		
	dike relocation	(incl. depoldering) - relocation towards a greater distance from the river course
	ecologically improved groynes	incl. lowering groynes, special shaping of groynes to optimize ecological benefits
	lowering floodplain/foreland	
	sediment addition	To compensate bed load deficit
	removing obstacles	bridge pylons, road dams etc.
7) Restauration – connectivity		

	removal of bank fixations	
	removal of dams and weirs	reestablishing longitudinal connectivity
	lateral floodplain reconnection measures	e.g. reconnecting side channels/oxbows; incl. measures like lowering of road-dams, lowering maintenance trails, widening of inlet structures
	channel, oxbow and pond creation	
	construction of fish passages	incl. rock ramps and bypasses
8) Restauration – renaturation		
	creation of natural habitat by transforming forest plantations	creation of natural habitats in areas that were covered by forest plantations before the implementation of the interventions
	creation of natural habitat by transforming agricultural land	creation of natural habitats in areas that were covered by agricultural land before the implementation of the interventions
	creation of natural habitat by transforming extraction sites	creation of natural habitats in areas that were covered by extraction sites (e.g. Clay-pits, gravel extraction, etc.) before the implementation of the interventions
	control of invasive alien species	ringbarking/cutting, biocides application, grazing/mowing, eradication of invasive alien biota
	creation of gravel banks	for initialization of natural succession (and evtl. gravel breeding habitats)
	removal of top soil	for initialization of natural succession, e.g. elimination of nutrient-rich top soil to create conditions for species rich wet meadows
	land use extensification	reduced intensity of use (mainly agriculture [mainly grassland], forestry, hunting and fishery)
9) Recreation		
	establishment, maintenance and usage of recreational infrastructure	e.g. construction of footpaths, info centers, access roads, observation hides, etc.
	recreational use of the floodplain	"off-track", e.g. fishermen, collectors, etc. [eventually to make an intervention out of it by specifying it is "restriction of access" - then the algebraic sign + and - must be switched]

Table 2. Ecosystem services considered in the assessment (from Haines-Young and Potschin, 2012, Maes et al., 2013)

Ecosystem service	Details
Provisioning services	
Terrestrial plants and animals for food	Crops, livestock and dairy farming, wild plants and animals and their products
Freshwater plants and animals for food	Fish (wild populations), aquaculture products, fresh water plants
Water for human consumption	Drinking water, domestic water use
Water for agricultural use	Irrigation water (consumptive) e.g. for crop production, water for livestock (consumptive) e.g. ponds
Water for industrial and energy uses	Industrial water, cooling water (e.g. for power production)
Biotic materials	Non-food vegetal fibres, non-food animal fibres, ornamental resources (e.g. bulbs, pearls, cut flowers), genetic resources (e.g. wild species used in breeding programmes), medicinal and cosmetic resources
Biomass based energy	Vegetal based resources (e.g. energy crops), animal based resources (e.g. fat)
Regulation and Maintenance	
Bioremediation	Remediation by plants or algae, remediation by micro-organisms, remediation by animals (e.g. filtration of particles using molluscs)
Air flow regulation	Rural microclimatic regulation (e.g. natural or planted vegetation that serves as shelter belts), urban microclimatic regulation (e.g. ventilation)
Water flow regulation	Attenuation of runoff and discharge rates (e.g. woodlands), water storage for flow regulation (e.g. flood plains and wetlands), coastal protection (e.g. mangroves, sea grasses)
Mass flow regulation	Erosion protection, avalanche and gravity flow protection (e.g. stabilisation of mudflows)
Atmospheric regulation	Global climate regulation (incl. C-sequestration), local & regional climate regulation
Water quality regulation	Water purification and oxygenation (e.g. natural or planted vegetation that serves nutrient retention)
Pedogenesis and soil quality regulation	Maintenance of soil fertility (e.g. N-fixing plants), maintenance of soil structure (e.g. soil organism activity)
Lifecycle maintenance, habitat and gene pool protection	Pollination, seed dispersal, maintaining nursery populations (e.g. habitat refuges)
Pest and disease control (incl. invasive alien species)	Biological control mechanisms
Cultural	
Aesthetic, Heritage	Landscape character (e.g. areas of outstanding natural beauty), cultural landscapes (e.g. sense of place)
Spiritual	Wilderness, naturalness (e.g. tranquility), sacred places or species
Recreation and community activities	Charismatic or iconic wildlife or habitats, prey for hunting, fishing or collecting, landscape character for recreational opportunities (e.g. surfing, hiking)
Information & knowledge	Scientific, educational

Relating interventions to ESS:

The assessment related each and every of the 38 interventions to each of the 21 ESS. We judged which kind of effect on ESS should be expected for typical floodplains of temperate Europe and chose among the options 'no effect', 'reducing effect', 'supporting effect', or 'ambiguous effect', i.e. reducing or supporting depending on the case specific conditions. When doing this judgement, the capacity to deliver an ESS after the implementation of an intervention was compared to the capacity to deliver an ESS before the intervention. This comparator can either be a floodplain in its natural state (e.g. for river regulation measures) or an unrestored strongly regulated river (e.g. for restoration measures). The judgement was complemented by a concise statement on the most important reasons for the decision by the experts (cf. Appendix 1).

The matrix was compiled building on expert knowledge, which, due to lack of evidence, is a commonly used approach when assessing relations to or effects on ESS (Burkhardt et al. 2009, 2012, Koschke et al. 2012, Hermann et al. 2013). The impact of each and every management intervention on the provision of each ecosystem services was discussed in groups at the workshop and complemented after the end of the workshop by a series of teleconferences in an iterative manner until consensus was reached. In detail, for each matrix cell, at least three experts were involved into the consultation. After the first draft of the matrix was completed, selected experts cross-checked the matrix horizontally and vertically to improve completeness of argumentation and consistency of judgments and arguments. Proposed improvements were discussed with one of the experts involved into the previous step until a consensus was achieved.

Assessing the multifunctionality of the bundles of interventions

The level of multifunctionality for all important interventions was assessed in terms of their effects on the ESS provision. For this purpose, a multifunctionality index was calculated that provides an idea of the multiple consequences of human actions together with the type-specific expert judgement on the impacts. The calculated index equals the difference of the number of positively and negatively affected ESS divided by the overall numbers of considered ESS. All ESS that were not affected or where the effects were judged as ambiguous received the value zero '0' and were accounted in the 'number of considered ESS'. Thus, the index ranged between -1 (all ESS were negatively affected) and +1 (all ESS were positively affected), and received the value of

±0 when the number of positively affected ESS equalled the number of negatively affected ones including the case when both numbers are zero and all ESS are not at all or ambiguously affected. Interventions with positive values of the multifunctionality index are supposed to increase the level of multifunctionality of the landscape, by a larger variety of ecosystem services provided as a result of the intervention. In this paper, we averaged the multifunctionality index of the interventions of the same bundle to obtain information on their multifunctionality. We calculated the multifunctionality index for all 21 ESS, and additionally for each of the three sections of ESS (i.e. provision, maintenance and regulation, cultural), comparing sector specific effects by the means of spider webs (De Groot et al. 2010, Hermann et al. 2013)

Results:

Effect of interventions on the multifunctionality of the floodplain

The matrix and the calculated multifunctionality index showed the effect of management interventions on the supply of ecosystem services in the floodplain (Table 3 and 4). Overall, the provision of the largest range of ESS is supported by renaturation measures such as *creating natural habitat by converting other land covers* or by *adding sediment*. Other interventions such as *dike relocation, lateral floodplain reconnection*, *creation of channels*, *oxbows and ponds* all benefit the multifunctionality of the floodplain considerably. While extensive production interventions in fishery, forestry, and agriculture showed slightly positive effects on multifunctionality, the intensive versions of these land uses had clear negative influence (Table 3 and 4). The most severe negative impact is to be expected by the *creation of navigational and settlement infrastructure*. Recreational interventions did not impact multifunctionality.

Table 3. Matrix of the expected effects of 38 floodplain interventions on the provision of 21 different ESS. “0”: no effect; “↘ “: reducing effect; “↗”; supporting effect; “↘↗”: ambiguous effect, i.e. reducing or supporting depending on the environmental conditions. See supplementary material for the justifications of these judgements.

Bundle of intervention	Intervention	Terrestrial plants and animals for food	Freshwater plants and animals for food	Water for human consumption	Water for agricultural use	Water for industrial and energy uses	Biotic materials	Biomass based energy	Bioremediation	Dilution and sequestration	Air flow regulation	Water flow regulation	Mass flow regulation	Atmospheric regulation	Water quality regulation	Pedogenesis and soil quality regulation	Lifecycle maintenance, habitat and gene pool protection	Pest and disease control (incl. invasive alien species)	Aesthetic, Heritage	Spiritual	Recreation and community activities	Information & knowledge
1	Surface water extraction	↘↗	↘	↘↗	↘↗	↘↗	↘	↘↗	↘	↘	0	↘↗	↘	↘	↘	↘	↘	↘↗	↘	↘	↘	↘↗
1	Groundwater extraction	↘↗	↘	↘↗	↘↗	↘↗	↘	↘↗	↘	↘	0	↘	0	↘	0	↘	↘	0	0	0	0	0
1	Mineral resource extraction	↘	↘↗	↘	↘↗	0	↘	↘	↘	↘	0	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘↗	↘↗
2	Settlement and traffic infrastructure	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	0	↘	↘	↘	↘	↘	↘	↘	↘	↘
2	Energy conversion	↘	↘	↘	↗	↗	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘↗	↘↗
2	Navigational infrastructure	↘	↘	↘	↘	↘	↘	0	↘	↘	0	↘	↘	0	↘	↘	↘	↘	↘	↘	↘↗	↘
3	Forestry intensive	↘	↘	↘	↘	↘	↘↗	↗	↘	↘	0	↘	↘	↘↗	↘	↘	↘	↘	↘	↘	↘	↘
4	Forestry extensive	0	0	0	0	0	↗	↗	0	0	0	0	0	0	0	0	↘	0	0	↘	↗	↘↗
3	Agriculture intensive	↗	↘	↘	↘	↘	↘↗	↗	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘
4	Agriculture extensive	↗	0	↘	0	0	↗	0	0	0	0	0	0	0	0	0	↘↗	↘	↘↗	↘	↗	0
4	Hunting	↗	0	0	0	0	↗	0	0	0	0	0	0	0	0	0	↘	↘↗	0	↘	↘↗	0
3	Fishery intensive	↘	↘↗	↘	0	0	↘	0	0	0	0	↘	↘	0	↘	0	↘	↘	↘	↘	↘	↘
4	Fishery extensive	0	↗	0	0	0	0	0	0	0	0	0	0	0	0	0	↗	0	↗	↗	↗	↗
5	channel corrections	↘↗	↘	↘	↘	↘	↘↗	↗	↘	↘	0	↘	↘	↘	↘	↘↗	↘	↘	↘	↘	↘↗	↘
5	dike construction	↗	↘	↘	0	↗	↗	↗	↘	↘	0	↘↗	↘	↘	↘	↘	↘	↘	↘	↘	↗	↘↗
5	bank/bed stabilization	↗	↘	↘↗	↘↗	↘↗	↘↗	↗	↘	↘	0	↘	↘	↘	↘	↘↗	↘	↘	↘	↘	↘↗	↘
5	sediment removal/dredging	0	↘	↘	↘	↘	0	0	0	↘↗	0	↘	↘	↘	↘↗	0	↘	0	0	↘	↘↗	0
5	detention basins	↘	↘	0	0	0	↘	↘	↘	↘	0	↘↗	↘	↗	↘	↘	↘	↘	↘↗	↘	↘↗	↘↗
5	controlled retention areas	↘	↘	↘	↘	↘	↘	0	↘	↘	0	↗	0	0	↘	↘	↘	↘	↘	↘	↘	0
6	dike relocation	↘↗	↗	↗	↗	↗	↘↗	↘	↗	↗	0	↗	↗	↗	↗	↗	↗	↘↗	↗	↗	↘↗	↗
6	ecologically improved groynes	0	↗	0	0	0	0	0	0	0	0	0	0	0	0	0	↗	0	0	0	↘	0
6	lowering floodplain/foreland	↘↗	↗	↗	↗	↗	↘↗	↘↗	↘↗	↗	0	↗	↗	↗	↗	↘↗	↘↗	↘↗	↘↗	↘↗	↘↗	↘↗
6	sediment addition	0	↗	↗	↗	↗	↗	↗	↗	↗	0	↗	↗	↗	↗	↗	↗	0	↗	↗	↘↗	↗
6	removing obstacles	0	↗	0	0	0	↗	0	↗	0	0	↗	↗	0	↗	↗	↗	0	↗	↗	↘	0
7	removal of bank fixations	↘	↗	↗	↗	↗	↘↗	↘	↗	↗	0	↗	↗	0	↗	↘↗	↗	↘↗	↗	↗	↘↗	↗
7	removal of dams and weirs	0	↗	0	0	0	0	0	↗	0	0	0	↗	0	↗	0	↗	↘↗	↘↗	↗	↘↗	0
7	lateral floodplain reconnection	0	↗	↗	↗	↗	↘↗	↘	↗	↗	0	↗	↗	↗	↗	↘↗	↗	↗	↗	↗	↘	↗
7	channel, oxbow and pond creation	↘	↗	↗	↗	↗	↘↗	↘	↗	↗	0	↗	↗	↗	↗	↗	↗	↘	↗	↗	↗	↗
7	construction of fish passages	0	↗	0	0	0	↗	0	0	0	0	0	0	0	0	0	↗	↘	0	0	↗	0
8	creating natural habitat from forest	↗	↗	↗	↗	↗	↘↗	↘	↗	↘↗	0	↗	↗	0	↗	↗	↗	↗	↗	↗	↘↗	↗
8	Creating natural habitat from agro land	↘	↗	↗	↗	↗	↘↗	↘	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↘↗	↗
8	Creating natural habitat from extraction sites	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↘↗	↗
8	control of invasive alien species	↗	↗	↘	0	0	↘↗	↘↗	↗	↘↗	0	↗	↗	0	0	↗	↗	↗	↗	↗	↗	↗
8	Creation of gravel banks	0	↗	0	0	0	0	0	↗	0	0	0	↗	0	0	↗	↗	↘	0	↗	↗	↗
8	elimination of top soil	↘	0	↘	0	0	↘	↘	↘	↘	0	↗	↗	↘	↗	↘↗	↗	↘↗	↘	0	0	↘↗
8	land use extensification	↘	↘↗	↗	0	0	↘↗	↘	↗	↗	0	0	↘	↗	↗	↗	↗	↗	↗	0	↗	↗
9	recreational infrastructure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	↘	↘	↘↗	↘	↗	↗
9	recreational use of the floodplain	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	↘	0	0	0	↗	0

Table 4. Multifunctionality index of the bundles of floodplain management interventions calculated for provisioning services (n=7), maintenance and regulation services (n=10), cultural services (n=4) and overall index (n=21).

Bundle of intervention	Intervention	Provisioning	Maintenance and regulation	Cultural	Overall (all ESS)
1	Surface water extraction	-0,29	-0,70	-0,75	-0,57
1	Groundwater extraction	-0,29	-0,60	0,00	-0,38
1	Mineral resource extraction	-0,57	-0,90	-0,50	-0,71
2	Settlement and traffic infrastructure	-1,00	-0,90	-1,00	-0,95
2	Energy conversion	-0,43	-1,00	-0,50	-0,71
2	Navigational infrastructure	-0,86	-0,80	-0,75	-0,81
3	Forestry intensive	-0,57	-0,80	-1,00	-0,76
3	Forestry extensive	0,29	-0,10	0,00	0,05
3	Agriculture intensive	-0,29	-1,00	-1,00	-0,76
4	Agriculture extensive	0,14	-0,10	0,00	0,00
4	Hunting	0,29	-0,10	-0,25	0,00
4	Fishery intensive	-0,43	-0,50	-1,00	-0,57
4	Fishery extensive	0,14	0,10	1,00	0,29
5	Channel corrections	-0,43	-0,80	-0,75	-0,67
5	Dike construction	0,29	-0,80	-0,25	-0,33
5	Bank/bed stabilization	0,14	-0,80	-0,75	-0,48
5	Sediment removal/dredging	-0,57	-0,40	-0,25	-0,43
5	Detention basins	-0,57	-0,60	-0,25	-0,52
5	Controlled retention areas	-0,86	-0,50	-0,75	-0,67
6	Dike relocation	0,43	0,80	0,75	0,67
6	Ecologically improved groynes	0,14	0,10	-0,25	0,05
6	Lowering floodplain/foreland	0,57	0,50	0,00	0,43
6	Sediment addition	0,86	0,80	0,75	0,81
6	Removing obstacles	0,29	0,60	0,25	0,43
7	Removal of bank fixations	0,29	0,60	0,75	0,52
7	Removal of dams and weirs	0,14	0,40	0,25	0,29
7	Lateral floodplain reconnection measures	0,43	0,80	0,50	0,62
7	Channel, oxbow and pond creation	0,29	0,70	1,00	0,62
7	Construction of fish passages	0,29	0,00	0,25	0,14
8	Creation of natural habitat by transforming forest plantations	0,57	0,70	0,75	0,67
8	Creation of natural habitat by transforming agricultural land	0,29	1,00	0,75	0,71
8	Creation of natural habitat by transforming extraction sites	1,00	1,00	0,75	0,95
8	Control of invasive alien species	0,14	0,60	1,00	0,52
8	Sediment addition	0,14	0,30	0,75	0,33
8	Elimination of top soil	-0,57	0,10	-0,25	-0,19
8	Land use extensification	-0,14	0,60	0,75	0,38
9	Establishment, maintenance and usage of recreational infrastructure	0,00	-0,20	0,25	-0,05
9	Recreational use of the floodplain	0,00	-0,10	0,25	0,00

Few interventions, such as *surface water extraction, groundwater extraction and mineral extraction* showed no positive effect on any ESS, maximally ambiguous effects could be described. Other measures like the *construction of detention basins* or *controlled retention areas* had only a positive effect on one single ESS (Table 3). Also the amount of ESS affected in any direction differed largely among the interventions with some of the previously mentioned most positive and most negative interventions affecting almost all ESS in one way or the other, while others, e.g. *recreational use of the floodplain* and *ecologically improved groynes* showed a targeted effect on only very few ESS (Table 3). Looking specifically at provisioning services, it is striking that the variety of provided services is threatened by interventions focused on production such as *intensive agriculture, fishery and forestry* while interventions related to restoration (e.g. *restoring natural habitat, small scale sediment addition, lateral floodplain reconnection*) and hydrological engeneering (e.g. *dike relocation*) affected many ESS positively (Table 3).

Effect of bundles of interventions on the multifunctionality of the floodplain

The effect of the nine bundles of interventions on the overall multifunctionality index was rather different (Fig. 1). The bundles ‘production-infrastructure’ and ‘production-intensive land use’ have the greatest negative effect on multifunctionality. ‘production-extraction’ and ‘hydrological engineering-regulation’ had a pronounced but less negative effect. The bundles ‘hydrological engineering-rehabilitation’, ‘restauration-connectivity’, and ‘restauration-renaturation’ have a clear positive impact, while overall effects of ‘production-extensive land use’ and ‘recreation’ were marginal (Fig. 1).

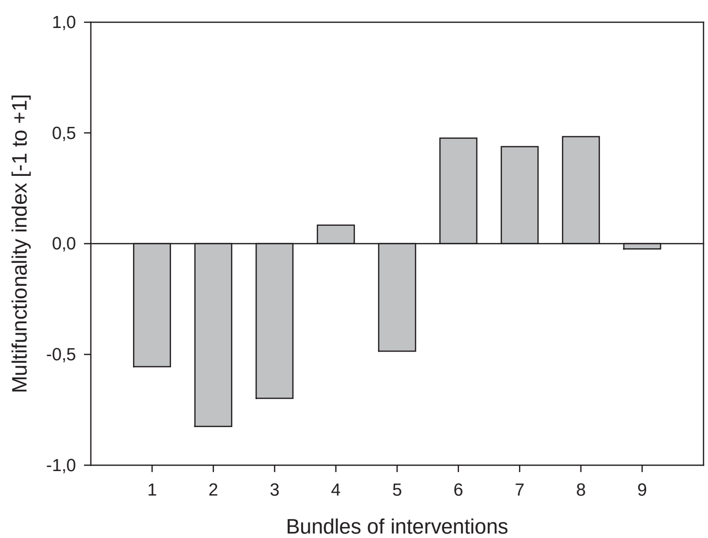

Figure 1. Effect of the nine bundles of interventions on the muntifunctionality of the floodplain. 1: Production – Extraction, 2: Production – Infrastructure, 3: Production - Intensive land use, 4: Production - Extensive land use, 5: Hydrological engineering – Regulation, 6: Hydrological engineering – Rehabilitation, 7: Restauration – Connectivity, 8: Restauration – Renaturation, 9: Recreation.

Effect of bundles of interventions on the multifunctionality within different ecosystem service categories

The effect on the provision of different ecosystem service (provisioning, maintenance and regulation, and cultural services) clearly differed among bundles of interventions (Fig. 2). Some of the bundles such as 'production-infrastructure', 'hydrological engineering-rehabilitation' and 'restauration-connectivity' had a similar impact on all three service categories while other such as 'production-intensive land use', 'hydrological engineering-regulation' and 'restauration-renaturation' displayed different effects among the service categories. The bundle 'restauration-renaturation' had strong positive impacts on cultural and regulation services while provisioning services obtained less (but still) benefit from these interventions. However, surprisingly many bundles caused clearly win-win-win or lose-lose-lose situations in terms of ESS for provision, regulation and maintenance, and culture (Fig. 2). For instance the bundles 'production-extraction', 'production-infratsructure' and 'production-intensive land use' obtained low multifunctionality values and thus negative effects on average ESS provision for all three sectors, even for provisioning services. Restoration measures (bundels 7 and 8) on the other hand lead to enhanced values of multifunctionality and average ESS provision for all three sectors. The enhancement was strongest in respect to culture and regulation and maintenance but also effects were also clearly positive for production services (Fig. 2).

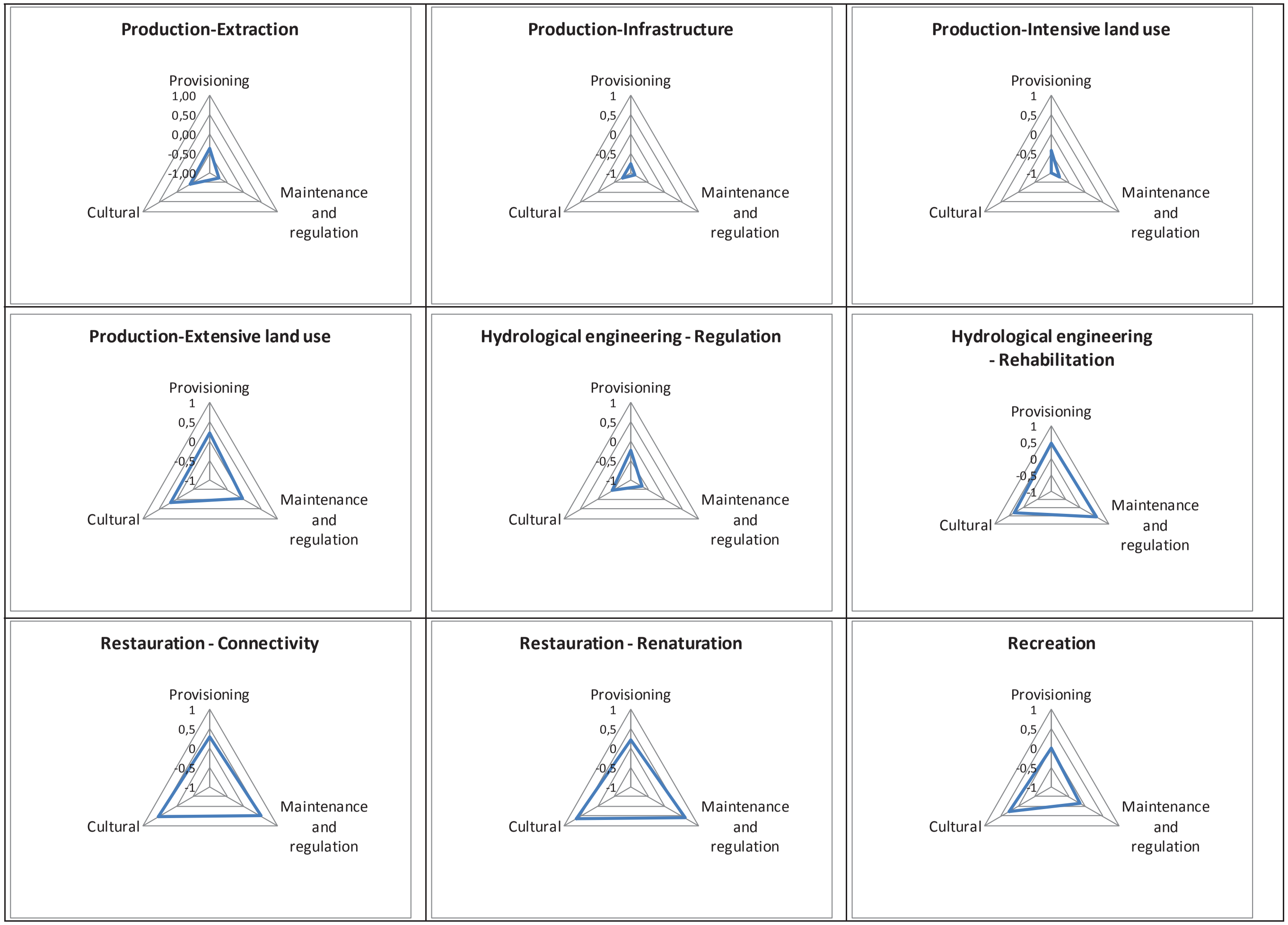

Figure 2. Impact of bundles of intervention on the provision of different ecosystem service categories

Summary and Conclusions

Floodplains of large European lowland rivers are landscapes where the need for the provision of multiple ecosystem services is particularly high. This work provides an overview of the impact of floodplain interventions on the provision of ecosystem services as assessed by expert consultation, covering 38 interventions (each of them including several specific measures) and 21 ESS. For each intervention, a multifunctionality index was calculated that specifies the overall impact on all considered ESS (-1: negative impact on all ESS; +1: positive impact on all ESS). The index was lowest for *settlements and traffic infrastructure* and highest for *creation of natural habitat from extraction sites*. Restauration and rehabilitation measures increase strongly the multifunctionality of the landscape and caused win-win situations for enhancing overall ESS provision, but also all three ESS-sectors (production, regulation and maintenance, and culture). Conventional regulation but also interventions related to extraction, infrastructure and intensive land use caused lose-lose situations with decrease in multifunctionality and negative effects for the average provision of all three sectors of ESS.

The applied methodological approach of assessing effects on ESS by expert knowledge, although commonly used in ESS-assessments has clear restrictions as the possibilities for providing quantitative results are limited without the use of clearly defined indicators and regarding datasets. However, this approach is based on expertise from researchers and practitioners of several European countries, and should be useful to provide an overview for decision makers at multiple governance levels. Further research should include the development of widely applicable indicators for the ecosystem services and generate long-term data sets to monitor effects on ESS provision in European floodplain landscapes.

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Appendix 1. Justifications for the effects of each interventions on each ESS.

1) Surface water extraction

Terrestrial plants and animals for food: +/- positive if water is used for agriculture, negative as water resources (e.g. ground water) get reduced

Freshwater plants and animals for food: - change and interruption of connected natural water habitats

Water for human consumption: +/- positive if water is used for human consumption, negative as water ressources (e.g. ground water) get reduced

Water for agricultural use: +/- positive if water is used for agriculture, negative as water ressources (e.g. ground water) get reduced, negative also downstreams

Water for industrial and energy uses: +/- positive if water is used for industrial and enegry use, negative as water ressources (e.g. ground water) get reduced

Biotic materials: - water is required for biotic materials, less water ressources are available, if water is used for other purposes

Biomass based energy: +/- positive if water is used for biofuels, etc., negative as water ressources (e.g. ground water) get reduced

Bioremediation: - natural processes get reduced/limited

Dilution and sequestration: - natural proceses get reduced/limited

Air flow regulation: 0

Water flow regulation: +/- surface water extraction can be used to decrease attenuation of runoff, but also disturbance of natural water flow dynamics

Mass flow regulation: - disturbance of natural erosion dynamics

Atmospheric regulation: - humidity of floodplain gets modified with potentially negative effects on local atmospheric regulation

Water quality regulation: - natural processes get limited, enrichment with oxygen reduced

Pedogenesis and soil quality regulation: - natural processes get reduced, natural soil generation gets reduced

Lifecycle maintenance, habitat and gene pool protection: - natural habitats get destroyed, natural processes get interrupted

Pest and disease control (incl. invasive alien species): -/+ alien species settle on new habitats (e.g. dry river beds), capacity of spread of aliens might get reduced (e.g. Fish)

Aesthetic, Heritage: - decrease of outstanding natural beauty

Spiritual: - loss of wilderness

Recreation and community activities: - recreation attractivity of non-natural rivers is less

Information & knowledge: -/+ natural history interrupted; creation of information due to intervention

2) Groundwater extraction

Terrestrial plants and animals for food: +/- positive if water is used for agriculture, negative as water resources get reduced

Freshwater plants and animals for food: - less water implies worse condition for fish (e.g. Spawning grounds)

Water for human consumption: +/- positive if water is used for human consumption, negative as water ressources get reduced

Water for agricultural use: +/- positive if water is used for agriculture, negative as water ressources get reduced, negative also downstreams

Water for industrial and energy uses: +/- positive if water is used for industrial and energy use, negative as water ressources get reduced

Biotic materials: - water is required for biotic materials, less water ressources are available, if water is used for other purposes

Biomass based energy: +/- positive if water is used for biofuels, etc., negative as water ressources get reduced

Bioremediation: - floodplains get dryer and natural processes get reduced/limited

Dilution and sequestration: - floodplains get dryer and natural processes get reduced/limited

Air flow regulation: 0

Water flow regulation: - floodplain gets dryer and natural retention capacity gets reduced

Mass flow regulation: 0

Atmospheric regulation: - humidity of floodplain gets modified with potentially negative effects on local atmospheric regulation

Water quality regulation: 0

Pedogenesis and soil quality regulation: - soils get dryer, with negative effects on pedogenesis

Lifecycle maintenance, habitat and gene pool protection: - floodplain gets dryer, natural processes get reduced

Pest and disease control (incl. invasive alien species): 0

Aesthetic, Heritage: 0

Spiritual: 0

Recreation and community activities: 0

Information & knowledge: 0

3) Mineral resource extraction

Terrestrial plants and animals for food: - loss of area

Freshwater plants and animals for food: +/- loss of area and potential pollution and disturbance; positive effect on fish when comparing flooded gravel pits to normal mix of land uses

Water for human consumption: - due water pollution

Water for agricultural use: +/- partly creation of open water surfaces suitable for agricultural uses, but also pollution

Water for industrial and energy uses: 0

Biotic materials: - loss of area

Biomass based energy: - loss of area

Bioremediation: - natural habitats get destroyed, natural processes get reduced/limited

Dilution and sequestration: - less vegetation

Air flow regulation: 0

Water flow regulation: - more area without vegetation, also impact on ground water

Mass flow regulation: - mass extraction, therefore mass flow regulation negative affected

Atmospheric regulation: - loss of vegetation has negative impact on CO_2-bilance and microclimatic effects

Water quality regulation: - loss of vegetation as water quality regulator

Pedogenesis and soil quality regulation: - less vegetation, less pedogenesis

Lifecycle maintenance, habitat and gene pool protection: - natural habitats get destroyed, natural processes get interrupted

Pest and disease control (incl. invasive alien species): - alien species settle on new habitats (e.g. open surfaces at extraction sites), alien spp. might get introduced with maschines

Aesthetic, Heritage: - decrease of outstanding natural beauty

Spiritual: - loss of wilderness and tranquility

Recreation and community activities: +/- artificial pond used for recreational purposes, otherwise reduction of attractivity for recreation

Information & knowledge: -/+ natural history interrupted; creation of information due to intervention

4) Terrestrial settlement and traffic infrastructure [except dikes, etc.]

Terrestrial plants and animals for food: - loss of area

Freshwater plants and animals for food: - drainage causes habitat loss

Water for human consumption: - built areas cause limitation of groundwater refill

Water for agricultural use: - built areas cause limitation of groundwater refill

Water for industrial and energy uses: - built areas cause limitation of groundwater refill

Biotic materials: - reduced due to buildt areas

Biomass based energy: - reduced due to built areas

Bioremediation: - natural habitats get destroyed, natural processes get reduced/limited

Dilution and sequestration: - reduced due to built areas

Air flow regulation: - built up areas are counterproductive for climate regulation; also pollution

Water flow regulation: - no retention

Mass flow regulation: 0 marginal effects into both directions possible

Atmospheric regulation: - built up areas are counterproductive for climate regulation; carbon sequestration reduced, pollution increased

Water quality regulation: - regulation capacity reduced, pollution increased

Pedogenesis and soil quality regulation: - sealing of surfaces

Lifecycle maintenance, habitat and gene pool protection: - natural habitats get destroyed, natural processes get interrupted

Pest and disease control (incl. invasive alien species): - alien species get dispersed/spread due to transport infrastructure and construction

Aesthetic, Heritage: - decrease in aesthetic value

Spiritual: - loss of wilderness and tranquility

Recreation and community activities: - landscape character and beauty is strongly decreased

Information & knowledge: - natural history interrupted

5) Energy conversion

Terrestrial plants and animals for food: - loss of area for agriculture, and for neighboring areas ground water table gets different and lack or surplus of water are the consequence; only due to further hydrological measures of big effort, agriculture is possible

Freshwater plants and animals for food: - redcued longitudinal connectivity of rivers, destruction of natural habitats

Water for human consumption: - reduced water quality, therefore less drinking water

Water for agricultural use: + creation of a big water reservoir that might provide water for agricultural use

Water for industrial and energy uses: + measure required to use water for energy production, additionally creation of a big water reservoir that might provide water for industrial use

Biotic materials: - loss of area for biotic materials

Biomass based energy: - loss of area for bioenergy plants

Bioremediation: - natural processes get reduced/limited

Dilution and sequestration: - reduced natural capacity for dilution and sequestration

Air flow regulation: - destruction of floodplain forest leads to decrease in natural wind shelter function, loss of running water in big rivers also related to loss of ventilation

Water flow regulation: - natural dynamics destroyed

Mass flow regulation: - natural erosion dynamics interrupted, causing large scale problems (e.g. deepening of river bed and lowering of ground water level, etc.)

Atmospheric regulation: - High methane-production in sediments of water reservoirs, increased fog and moisture, decreased ventilation

Water quality regulation: - reduced water purification capacity

Pedogenesis and soil quality regulation: - loss of natural floodplain areas where pedogenesis did occur

Lifecycle maintenance, habitat and gene pool protection: - natural habitats get destroyed, natural processes get interrupted

Pest and disease control (incl. invasive alien species): - reduction of habitat for natural pest control agents (plants, animals); eventually introduction of propagules of IAS due to construction works

Aesthetic, Heritage: - decrease in aesthetic value

Spiritual: - decrease of naturalness and wilderness

Recreation and community activities: +/- increased water sport options, decreased attractiveness related to natural beauty

Information & knowledge: +/- natural history gets interrupted, but important for technical education

6) Navigational infrastructure

Terrestrial plants and animals for food: - wild plants and animals and their products; evtl. positive effects on agriculture, but probably rare or marginal

Freshwater plants and animals for food: - mainly wild fish populations

Water for human consumption: - groundwater refill gets limited

Water for agricultural use: - groundwater refill gets limited

Water for industrial and energy uses: - groundwater refill gets limited due to limitation of fluctuation, and colmation of river beds

Biotic materials: - wild plants and animals and their fibers get reduced, if natural floodplain forest get destroyed; (secondary use as timber plantation might cause positive ESS supply)

Biomass based energy: 0

Bioremediation: - natural processes get limited due to navigation

Dilution and sequestration: - natural processes get limited due to navigation

Air flow regulation: 0

Water flow regulation: - reduction of dynamics of natural water flow

Mass flow regulation: - reduction of natural erosion dynamics

Atmospheric regulation: 0

Water quality regulation: - natural processes get limited due to navigation, enrichment with oxygen reduced

Pedogenesis and soil quality regulation: - natural processes get limited due to navigation

Lifecycle maintenance, habitat and gene pool protection: - natural habitats might get destroyed, natural processes get interrupted

Pest and disease control (incl. invasive alien species): - alien species get dispersed/spread due to navigation and construction machines and settle on new habitats (e.g. Riprap)

Aesthetic, Heritage: - decrease of outstanding natural beauty

Spiritual: - limitation of wilderness

Recreation and community activities: -/+ landscape character and beauty is decreased, accessability and usability are increased (less important)

Information & knowledge: - natural history interrupted

7) Forestry intensive

Terrestrial plants and animals for food: - natural floodplain might provide more berries, funghi, etc. than forest plantations; regular destruction of soil surface by the heavy mechanisms affects growth of plants; increase of invasive species

Freshwater plants and animals for food: - several adverse effects, mainly freshwater habitat loss

Water for human consumption: - water consumption due to intensive forestry, and additionally eventually loss of purification capacity

Water for agricultural use: - water gets used for intensive forestry, demand for ESS increases, therefore net-supply decreases

Water for industrial and energy uses: - water gets used for intensive forestry, demand for ESS increases, therefore net-supply decreases

Biotic materials: +/- biomass of timber very strongly increases, but diversity of biotic materials clearly decreases

Biomass based energy: + if wood counts as biomass based energy

Bioremediation: - natural habitats get destroyed, natural processes get reduced/limited

Dilution and sequestration: - / + dilution probably less but sequestration higher

Air flow regulation: 0

Water flow regulation: - loss of natural retention area and loss of natural dynamics

Mass flow regulation: - interruption of natural mass flow dynamics

Atmospheric regulation: +/- more O_2 release and more CO_2 fixation, but eventually negative effects on humidity level, because plantations are much dryer

Water quality regulation: - dryer, less bioremediation

Pedogenesis and soil quality regulation: - natural habitats get destroyed, natural processes get interrupted

Lifecycle maintenance, habitat and gene pool protection: - natural habitats get destroyed, natural processes get interrupted

Pest and disease control (incl. invasive alien species): - alien species used for forest plantation, including non-natural conditions of understory; loss of natural habitat

Aesthetic, Heritage: - decrease of outstanding natural beauty, decrease of landscape variabilty

Spiritual: - loss of wilderness and tranquility

Recreation and community activities: - loss of attractivity for recreation in monoculture forest

Information & knowledge: - interruption of natural history

8) Forestry extensive

Terrestrial plants and animals for food: 0 extensive forest might provide some berries and funghi as food but no significant difference to floodplain

Freshwater plants and animals for food: 0

Water for human consumption: 0

Water for agricultural use: 0

Water for industrial and energy uses: 0

Biotic materials: + timber extraction without negative side-effects on other biotic materials

Biomass based energy: + wood availability increases

Bioremediation: 0

Dilution and sequestration: 0

Air flow regulation: 0

Water flow regulation: 0

Mass flow regulation: 0

Atmospheric regulation: 0

Water quality regulation: 0

Pedogenesis and soil quality regulation: 0

Lifecycle maintenance, habitat and gene pool protection: - decreased biodiversity, e.g. dead wood species

Pest and disease control (incl. invasive alien species): 0

Aesthetic, Heritage: 0

Spiritual: - loss of wilderness and tranquility

R**ecreation and community activities**: + accessabiliy increases

Information & knowledge: -/+ information about natural floodplain diminishes, but actvities and natural ecosystems might still be used for educational activities

9) Agriculture intensive

Terrestrial plants and animals for food: + although diversity of food might be reduced, but amount of food very clearly increased

Freshwater plants and animals for food: - freshwater habitat loss; contamination with pesticides and fertilisers

Water for human consumption: - water quality gets reduced

Water for agricultural use: - water gets used for intensive agriculture, demend for ESS increases, therefore net-supply decreases

Water for industrial and energy uses: - water used for agriculture, therefore less water left for industry

Biotic materials: +/- straw production increased, but diversity of biotic materials clearly decreased

Biomass based energy: +

Bioremediation: - natural habitats get destroyed, natural processes get reduced/limited

Dilution and sequestration: - normally negative effect, (effects of N-fixing plants only marginally positive when compared to a natural floodplain)

Air flow regulation: - decrease due to loss of moisture and loss of vegetation

Water flow regulation: - loss of natural retention area and loss of natural dynamics

Mass flow regulation: - interruption of natural mass flow dynamics

Atmospheric regulation: - crops and livestock negative

Water quality regulation: - reduction of water quality

Pedogenesis and soil quality regulation: - normally negative effect, (effects of N-fixing plants only marginally positive when compared to a natural floodplain)

Lifecycle maintenance, habitat and gene pool protection: - natural habitats get destroyed, natural processes get interrupted

Pest and disease control (incl. invasive alien species): - alien species used for agriculture; and additionally loss of natural pest control due to insecticides and loss of natural habitat

Aesthetic, Heritage: - decrease of outstanding natural beauty (although specific agricultural uses such as rice paddies might be an important cultural heritage)

Spiritual: - loss of wilderness and tranquility

Recreation and community activities: - loss of attractiveness for recreation

Information & knowledge: - interruption of natural history

10) Agriculture extensive

Terrestrial plants and animals for food: + extensive agriculture produces food

Freshwater plants and animals for food: 0

Water for human consumption: - competitive use for water preserves

Water for agricultural use: 0

Water for industrial and energy uses: 0

Biotic materials: + eventual increase due to lether, whool, feathers of grazing animals

Biomass based energy: 0 although cattle dung might be used, but probably not big amount of ESS delivery

Bioremediation: 0

Dilution and sequestration: 0

Air flow regulation: 0

Water flow regulation: 0

Mass flow regulation: 0

Atmospheric regulation: 0 (although on large spatial scales it might be that extensive agriculture increases methane-emmision)

Water quality regulation: 0 (too marginal effetcs on water purification capacity)

Pedogenesis and soil quality regulation: 0 (only very marginal effetcs on pedgenesis)

Lifecycle maintenance, habitat and gene pool protection: +/- extensive grazing causes landscape heterogeneity, and increases biodiversity (e.g. floodplain meadows); compared to totally natural situations extensive agriculture might also have reverse effects

Pest and disease control (incl. invasive alien species): - potentially introduction of aliens, pests or diseases by livestock

Aesthetic, Heritage: +/- extensive agricultue is an important aspect of cultural heritage and landscape character, but so was also the natural floodplain

Spiritual: - loss of wilderness and tranquility

Recreation and community activities: + extensive grazing might be attractive for recreationists and might introduce recreation possibilities and increase accessability

Information & knowledge: 0 (eventually traditional knowledge of sustainable agriculture)

11) Hunting

Terrestrial plants and animals for food: + game meat available for food

Freshwater plants and animals for food: 0

Water for human consumption: 0

Water for agricultural use: 0

Water for industrial and energy uses: 0

Biotic materials: + deer head, horns, fell, skin

Biomass based energy: 0

Bioremediation: 0

Dilution and sequestration: 0

Air flow regulation: 0

Water flow regulation: 0

Mass flow regulation: 0

Atmospheric regulation: 0

Water quality regulation: 0

Pedogenesis and soil quality regulation: 0

Lifecycle maintenance, habitat and gene pool protection: - disturbance and direct persecution of non-game animals (e.g. predators), problems caused by game species such as habitat competition, damage of young trees, disturbance of ecologial equilibrium due to overabundance

Pest and disease control (incl. invasive alien species): -/+ alien spp. introduced for hunting purposes and kept at artificially high population level; control of pest species in the frame of hunting activities

Aesthetic, Heritage: 0

Spiritual: - loss of wilderness and tranquility

Recreation and community activities: +/- hunting is an important form of recreatrion but limits probably other forms of recreation

Information & knowledge: 0

12) Fishery intensive

Terrestrial plants and animals for food: - maybe loss of area for food production due to construction of fish ponds

Freshwater plants and animals for food: +/- fish ponds, and fish-stocking should increase available fish biomass, but comercial extraction of fish is of course negative

Water for human consumption: - water quality might get reduced

Water for agricultural use: 0

Water for industrial and energy uses: 0

Biotic materials: - maybe loss of area for biotic material production due to construction of fish ponds

Biomass based energy: 0

Bioremediation: 0

Dilution and sequestration: 0

Air flow regulation: 0

Water flow regulation: - fish ponds may lead to interruption of lateral connectivity, and consequently less water retention

Mass flow regulation: - interruption of natural mass flow dynamics

Atmospheric regulation: 0

Water quality regulation: - water quality might get reduced

Pedogenesis and soil quality regulation: 0

Lifecycle maintenance, habitat and gene pool protection: - destruction of natural habitat for fish ponds, and disturbance of ecological equilibrium due to fish stocking

Pest and disease control (incl. invasive alien species): - fish stocking with alien species

Aesthetic, Heritage: - decrease of outstanding natural beauty (mainly due to artificial fish ponds)

Spiritual: - loss of wilderness and naturalness

Recreation and community activities: - commercial fishing blocks recreation activities

Information & knowledge: - loss of natural habitat and loss of natural dynamics in fish population

13) Fishery extensive

Terrestrial plants and animals for food: 0

Freshwater plants and animals for food: + better conditions for fish spawning, while extensive small-scale hobby-fishing should not affect the populations

Water for human consumption: 0

Water for agricultural use: 0

Water for industrial and energy uses: 0

Biotic materials: 0

Biomass based energy: 0

Bioremediation: 0

Dilution and sequestration: 0

Air flow regulation: 0

Water flow regulation: 0

Mass flow regulation: 0

Atmospheric regulation: 0

Water quality regulation: 0

Pedogenesis and soil quality regulation: 0

Lifecycle maintenance, habitat and gene pool protection: + spawning gravel (etc.) should improve habitat conditions for aquatic organisms

Pest and disease control (incl. invasive alien species): 0

Aesthetic, Heritage: + extensive fishing is part of cultural heritage of floodplain

Spiritual: + increase of naturalness due to habitat improvements

Recreation and community activities: + conditions for recreation activities (e.g. Fishing) improved due to spawning gravel

Information & knowledge: + extensive fishing is a way of transfer of traditional knowledge

14) Channel corrections

Terrestrial plants and animals for food: +/- area gained for agriculture, area lost for wild plants and animals

Freshwater plants and animals for food: - mainly wild fish populations

Water for human consumption: - groundwater refill gets limited

Water for agricultural use: - groundwater refill gets limited

Water for industrial and energy uses: - groundwater refill gets limited

Biotic materials: -/+ wild plants and animals and their fibers get reduced, as natural dynamics decline; eventually qualitative worse, but quantitative more fibers to be extracted as there is more area

Biomass based energy: + more space for bioenergy crops

Bioremediation: - natural processes get reduced/limited

Dilution and sequestration: - natural processes get limited

Air flow regulation: 0

Water flow regulation: - reduction of dynamics of natural water flow

Mass flow regulation: - reduction of natural erosion dynamics and related large scale natural erosion equilibrium

Atmospheric regulation: - forest gets dryer, less cabon sequestration, increased carbon emission

Water quality regulation: - natural proceses get limited, enrichment with oxygen reduced

Pedogenesis and soil quality regulation: +/- stable conditions are better for pedogenesis, frequency of fertilizing inundations gets lower

Lifecycle maintenance, habitat and gene pool protection: - natural habitats get destroyed, natural processes get interrupted

Pest and disease control (incl. invasive alien species): - alien species settle on artificial habitats created by constructions

Aesthetic, Heritage: - decrease of outstanding natural beauty

Spiritual: - limitation of wilderness

Recreation and community activities: -/+ landscape character and beauty are decreased, accessability/usability might be increased (less important),

Information & knowledge: - natural history interrupted

15) Dike construction

Terrestrial plants and animals for food: + more stable conditions for agriculture

Freshwater plants and animals for food: - building new dikes implies habitat loss for fish (especially for spawning?)

Water for human consumption: - reduced infiltration (mainly outside of the dike)

Water for agricultural use: 0

Water for industrial and energy uses: + for energy uses (therefore dikes are often built); eventually also positive for other industrial uses

Biotic materials: +/- abundance of biotic materials will increase and be more accessible, but diversity (incl. genetic diversity) of biotic materials will decrease

Biomass based energy: + conditions for most bioenergy crops (e.g. Populus; energy crops(?)) will improve

Bioremediation: - natural processes get reduced/limited, and natural habitat area may get reduced

Dilution and sequestration: - natural processes get reduced/limited

Air flow regulation: 0

Water flow regulation: -/+ for local floodplain positive, downstreams negative; overall consequences for floodplain (inside and outside the dike) regarding water storage capacity are negative

Mass flow regulation: - reduction of natural erosion dynamics and related large scale natural erosion equilibrium

Atmospheric regulation: - forest gets dryer, less cabon sequestration, increased carbon emission

Water quality regulation: - reduced water purification (mainly outside dike)

Pedogenesis and soil quality regulation: - reduced retention area, worse conditions for pedogenesis inside the dike due to increased discharge, outside the dike decrease of soil fertility

Lifecycle maintenance, habitat and gene pool protection: - natural habitats get destroyed, natural processes get interrupted

Pest and disease control (incl. invasive alien species): - dikes are beneficial for invasives. They are dispersion corridors and cause habitat changes that might benefit invasive species

Aesthetic, Heritage: - decrease in aesthetic value

Spiritual: - loss of wilderness and naturalness

Recreation and community activities: + creates recreation options

Information & knowledge: +/- increases accesability into areas for ecotourism; changes caused by dikes might generate information and knowledge; natural history gets interrupted

16) Bank/bed stabilization

Terrestrial plants and animals for food: + more stable conditions for agriculture, edible wildlife in hardwood forest should also be increased (if any effect then a positive one)

Freshwater plants and animals for food: - reduction of habitat quality and connectivity mainly related to spawning grounds (more for rheophile species)

Water for human consumption: -/+ reduced infiltration due to clogging with fine sediment; evtl. positive effects for technical constructions for drinkwater extraction and drinkwater quality

Water for agricultural use: -/+ reduced infiltration due to clogging with fine sediment; evtl. positive effects for technical constructions for water extraction

Water for industrial and energy uses: -/+ reduced infiltration due to clogging with fine sediment; evtl. positive effects for technical constructions for water extraction

Biotic materials: +/- abundance of biotic materials will increase and be more accessible, but diversity (incl. genetic diversity) of biotic materials will decrease

Biomass based energy: + conditions for most bioenergy crops (e.g. Populus; energy crops(?)) will improve

Bioremediation: - natural river dynamics get reduced

Dilution and sequestration: - mostly negative because water gets more filtered if natural dynamics prevail

Air flow regulation: 0

Water flow regulation: - clogging and other effects caused by loss of natural dynamics

Mass flow regulation: - reduction of natural erosion dynamics and related large scale natural erosion equilibrium

Atmospheric regulation: - forest gets dryer with consequences for local atmospheric water balance

Water quality regulation: - water gets more filtered if natural dynamics prevail

Pedogenesis and soil quality regulation: +/- stable conditions are better for pedogenesis, frequency of fertilizing inundations gets lower

Lifecycle maintenance, habitat and gene pool protection: - natural habitats get destroyed, natural processes get interrupted

Pest and disease control (incl. invasive alien species): - alien species settle on artificial habitats created by constructions, which are also good corridors for alien species

Aesthetic, Heritage: - decrease in aesthetic value

Spiritual: - loss of wilderness and naturalness

Recreation and community activities: +/- accessability increases; naturalness and attractiveness eventually decrease

Information & knowledge: - natural history interrupted

17) Sediment removal/dredging

Terrestrial plants and animals for food: 0

Freshwater plants and animals for food: - negative effects on structure of water body, disturbance, destruction of important habitats for freshwater species

Water for human consumption: - potentially lowering of ground water table

Water for agricultural use: - potentially lowering of ground water table

Water for industrial and energy uses: - potentially lowering of ground water table

Biotic materials: 0

Biomass based energy: 0

Bioremediation: 0 (eventually very short term disturbance of biofilms, but they probably soon recover)

Dilution and sequestration: +/- depending on local conditions and amount of increase of flow, it might have positive or negative effects

Air flow regulation: 0

Water flow regulation: - reduced retention capacity

Mass flow regulation: - reduction of natural erosion dynamics and related large scale natural erosion equilibrium

Atmospheric regulation: - drying out of floodplain with consequences for atmospheric humidity

Water quality regulation: +/- depending on local conditions and amount of increase of flow, it might have positive or negative effects

Pedogenesis and soil quality regulation: 0

Lifecycle maintenance, habitat and gene pool protection: - homogenization of habitat conditions in the river

Pest and disease control (incl. invasive alien species): 0

Aesthetic, Heritage: 0 (despite temporal disturbance caused by works)

Spiritual: - decrease of naturalness and tranquility

Recreation and community activities: -/+ more artificial and less attractive; but might be more suitable for water sports

Information & knowledge: 0

18) Detention basins

Terrestrial plants and animals for food: - loss of productive area, loss of productivity

Freshwater plants and animals for food: - negative effects on structure of water body, loss of longitudinal connectivity, evtl. loss of habitat

Water for human consumption: 0 eventual effects are too marginal

Water for agricultural use: 0 although partly used as irrigation water; eventually larger importance in dry regions

Water for industrial and energy uses: 0 eventual effects are too marginal

Biotic materials: - due to loss of area (eventually to marginal)

Biomass based energy: - loss of area for potential land use for biofuels

Bioremediation: - natural processes get reduced/limited

Dilution and sequestration: - natural processes get reduced/limited

Air flow regulation: 0

Water flow regulation: +/- natural dynamics reduced, but mitigation of extreme events

Mass flow regulation: - reduction of natural erosion dynamics and related large scale natural erosion equilibrium

Atmospheric regulation: + eventual extension of wetland areas in urban context

Water quality regulation: - natural processes get limited, enrichment with oxygen reduced

Pedogenesis and soil quality regulation: - natural processes get reduced, natural soil generation gets reduced

Lifecycle maintenance, habitat and gene pool protection: - / + normally natural conditions get reduced, but in intensive agricultural areas or cities, eventually detention basins can serve as refuges for wetland species

Pest and disease control (incl. invasive alien species): - alien species settle on artificial habitats created by constructions

Aesthetic, Heritage: -/+ decrease of outstanding natural beauty (although in cities and in agricultural areas it might be positive)

Spiritual: - decrease of naturalness

Recreation and community activities: +/- accessability increases; naturalness and attractiveness eventually decrease

Information & knowledge: +/-, natural history interrupted; educational opportunities and accessability increased

19) Controlled retention areas

Terrestrial plants and animals for food: - loss of productive area, loss of natural habitat

Freshwater plants and animals for food: - negative effects on structure of water body, loss of connectivity, evtl. loss of habitat

Water for human consumption: - groundwater refill gets limited/reduced

Water for agricultural use: - groundwater refill gets limited/reduced

Water for industrial and energy uses: - groundwater refill gets limited/reduced

Biotic materials: - less natural habitat, less productivity

Biomass based energy: 0

Bioremediation: - natural processes get reduced/limited, and natural habitat area may get reduced

Dilution and sequestration: - natural processes get reduced/limited

Air flow regulation: 0

Water flow regulation: + mitigation of extreme events (evtl. negative impact on natural dynamics of local water bodies comparatively small but possible)

Mass flow regulation: 0

Atmospheric regulation: 0

Water quality regulation: - natural processes get limited/reduced, enrichment with oxygen reduced

Pedogenesis and soil quality regulation: - natural proceses get reduced, natural soil generation gets reduced

Lifecycle maintenance, habitat and gene pool protection: - natural habitats get destroyed, natural processes get interrupted

Pest and disease control (incl. invasive alien species): - alien species benefit from unnatural constructions

Aesthetic, Heritage: - less outstanding natural beauty than original river

Spiritual: - decrease of naturalness, wilderness and tranquility due to increased control and presence of technical equipment and buildings

Recreation and community activities: - decrease of retention possibilities possible, increase not

Information & knowledge: 0

20) Dike relocation

Terrestrial plants and animals for food: +/- wild plants and animals increase, agricultural land use reduced/impacted

Freshwater plants and animals for food: + increase of habitats

Water for human consumption: + groundwater refill gets increased

Water for agricultural use: + groundwater refill gets increased

Water for industrial and energy uses: + groundwater refill gets increased

Biotic materials: +/- wild plant- and animal products increase, agricultural and forestry products reduced/impacted

Biomass based energy: - area lost for bioenergy crops

Bioremediation: + natural processes get increased

Dilution and sequestration: + natural processes get increased

Air flow regulation: 0

Water flow regulation: + natural dynamics restored, river flow positively influenced

Mass flow regulation: + eventual increase of natural erosion dynamics; and reduced bed erosion

Atmospheric regulation: + reduced carbon emissions due to increased moisture and floodplain forest, and other local effects

Water quality regulation: + natural proceses increased, enrichment with oxygen increased

Pedogenesis and soil quality regulation: + natural processes increased, gain of rare and valuable floodplain soil

Lifecycle maintenance, habitat and gene pool protection: + natural habitat area and diversity increases, natural processes get restored in the additional floodplain area

Pest and disease control (incl. invasive alien species): +/- restoration of natural conditions; increase of IAS due to increase of lateral connectivity

Aesthetic, Heritage: + landscape character is restored

Spiritual: + increase of naturalness and wilderness

Recreation and community activities: +/-, accessability decreases; naturalness increases (therefore also attractiveness for recreational use)

Information & knowledge: + eventually suitable for wildlife programmes

21) Ecologically improved groynes

Terrestrial plants and animals for food: 0

Freshwater plants and animals for food: + improvement of conditions for fish and their habitat

Water for human consumption: 0

Water for agricultural use: 0

Water for industrial and energy uses: 0

Biotic materials: 0

Biomass based energy: 0

Bioremediation: 0

Dilution and sequestration: 0

Air flow regulation: 0

Water flow regulation: 0

Mass flow regulation: 0

Atmospheric regulation: 0

Water quality regulation: 0

Pedogenesis and soil quality regulation: 0

Lifecycle maintenance, habitat and gene pool protection: + improved habitat conditions for aquatic organisms

Pest and disease control (incl. invasive alien species): 0 (possitive effects of dead wood groynes are possible)

Aesthetic, Heritage: 0

Spiritual: 0

Recreation and community activities: - reduced accessability e.g. for fishermen

Information & knowledge: 0

22) Lowering floodplain/foreland

T**errestrial plants and animals for food**: +/- improved flooding conditions, loss of cultivated area

Freshwater plants and animals for food: + increase of aquatic habitats (and improved flooding conditions)

Water for human consumption: + better infiltration, improved ground water refill

Water for agricultural use: + better infiltration, improved ground water refill

Water for industrial and energy uses: + better infiltration, improved ground water refill

Biotic materials: +/- increasing genetic ressources, decreasing timber production area)

Biomass based energy: -/+ depending on wood fuel species, decreased hard wood species, increased soft wood species

Bioremediation: +/- first destruction of habitat and natural processes, later natural processes should recover finally be improved

Dilution and sequestration: + better purification

Air flow regulation: 0

Water flow regulation: + more retetion area and greater discharge capacity

Mass flow regulation: + increased natural erosion, reduced river bed erosion, increased natural erosion processes

Atmospheric regulation: + more humidity, less C loss

Water quality regulation: + better quality due to enhanced natural processes

Pedogenesis and soil quality regulation: +/- dynamic processes are increased, but loss of soils by the lowering itselfs

Lifecycle maintenance, habitat and gene pool protection: +/- loss of soils (habitat and vegetation) by the lowering, but finally dynamic processes get increased

Pest and disease control (incl. invasive alien species): +/- restoration of natural conditions, impact of construction measure temporarily positiv for invasivs

Aesthetic, Heritage: +/- increase of natural beauty, natural heritage might get loss

Spiritual: +/- first decrease but finally increase of naturalness and wilderness

Recreation and community activities: +/- increased attractiveness, reduced accessability

Information & knowledge: +/- additional landscape character is used for educational purposes, natural history interrupted

23) Sediment addition

Terrestrial plants and animals for food: 0

Freshwater plants and animals for food: + improved spawning and nursery conditions for fish

Water for human consumption: + inhibits lowering of ground water table, thus positive for water availability

Water for agricultural use: + inhibits lowering of ground water table, thus positive for water availability

Water for industrial and energy uses: + inhibits lowering of ground water table, thus positive for water availability

Biotic materials: + inhibits drying of floodplain and thus maintains diversity (and productivity) regards biotic materials

Biomass based energy: + inhibits drying of floodplain and thus maintains diversity (and productivity) regards biofuels (and energy crops)

Bioremediation: + maintains natural conditions and natural processes and dynamics

Dilution and sequestration: + maintains natural conditions and natural processes and dynamics

Air flow regulation: 0

Water flow regulation: + natural water dynamics in floodplains and area of retention maintained

Mass flow regulation: + increased sediment loads lead to reduced erosion

Atmospheric regulation: + maintenance of humidity in the atmorsphere

Water quality regulation: + maintains natural conditions and natural processes and dynamics realted to water quality regulation

Pedogenesis and soil quality regulation: + maintains natural conditions, natural processes and dynamics realted to pedogenesis

Lifecycle maintenance, habitat and gene pool protection: + maintains natural conditions, natural habitats and high beta-diversity of floodplains

Pest and disease control (incl. invasive alien species): 0

Aesthetic, Heritage: + maintenance of landscape character

Spiritual: + maintenance of wilderness

Recreation and community activities: +/- maintains good conditions for water sports, potentially negative for terrestrial accessability

Information & knowledge: + maintains natural floodplain ecosystems

24) Removing obstacles

Terrestrial plants and animals for food: 0 the obstacles has so small size the effect is nearly

Freshwater plants and animals for food: + increased natural water regime

Water for human consumption: 0

Water for agricultural use: 0

Water for industrial and energy uses: 0

Biotic materials: + /- more area for wild plants; negative for forestry

Biomass based energy: 0

Bioremediation: + increased capacity of flow through areas

Dilution and sequestration: 0

Air flow regulation: 0 microclimatic effects are positive only on small scale

Water flow regulation: + for naturalness, negative if decreased retention is resulting

Mass flow regulation: + positive effects for natural erosion

Atmospheric regulation: 0

Water quality regulation: + bioredimation increased, oxygen enrichment increased

Pedogenesis and soil quality regulation: + natural floodplain conditions restablished

Lifecycle maintenance, habitat and gene pool protection: + natural habitat area and diversity increases, natural processes get restored

Pest and disease control (incl. invasive alien species): 0

Aesthetic, Heritage: + increase of outstanding natural beauty

Spiritual: + increase of wilderness

Recreation and community activities: - reduced accessibilty

Information & knowledge: 0

25) Removal of bank fixations

Terrestrial plants and animals for food: - conditions for agriculture become more unstable

Freshwater plants and animals for food: + increased habitat quality and connectivity mainly related to spawning grounds (more for rheophile species)

Water for human consumption: + probably at least some positive effect related to increased ground water level

Water for agricultural use: + probably at least some positive effecst related to increased ground water level

Water for industrial and energy uses: + probably at least some positive effects related to increased ground water level

Biotic materials: +/- abundance of biotic materials will decrease and be less accessible, but diversity (incl. genetic diversity) of biotic materials will increase

Biomass based energy: - conditions for most bioenergy crops (e.g. Populus; energy crops(?)) will become worse and less stable

Bioremediation: + recovery of natural dynamics

Dilution and sequestration: + mostly positive because water gets more filtered if natural dynamics prevail

Air flow regulation: 0

Water flow regulation: + increase of retention capacity and natural dynamics

Mass flow regulation: + increase of natural erosion dynamics and related large scale natural erosion equilibrium (at local scale it might happen that negative erosion effects occur, but natural erosion equilibrium is the best solution)

Atmospheric regulation: 0

Water quality regulation: + improved filtration capacity

Pedogenesis and soil quality regulation: +/- stable conditions are better for pedogenesis, but frequency of fertilizing inundations gets higher

Lifecycle maintenance, habitat and gene pool protection: + natural habitat area and diversity increases, natural processes get restored

Pest and disease control (incl. invasive alien species): +/- increase of natural dynamics including natural pest control; introduction of propagules due to construction works

Aesthetic, Heritage: + increased aesthetics

Spiritual: + increase of naturalness and wilderness

Recreation and community activities: +/- increased recreation potential ("nice beaches"), eventually decreased accesability,

Information & knowledge: + important for education

26) Removal of dams and weirs

Terrestrial plants and animals for food: 0

Freshwater plants and animals for food: + very important measure for fish populations (both local and migrating fish species)

Water for human consumption: 0 eventually locally decreased infiltration, and eventually compensated by increased natural water dynamics

Water for agricultural use: 0 eventually locally decreased infiltration, and eventually compensated by increased natural water dynamics

Water for industrial and energy uses: 0 eventually locally decreased infiltration, and eventually compensated by increased natural water dynamics

Biotic materials: 0

Biomass based energy: 0

Bioremediation: + natural processes get restored

Dilution and sequestration: 0

Air flow regulation: 0

Water flow regulation: 0 (in rare situations, it might be possible that removal of dams and weirs causes negative impact on water flow regulation)

Mass flow regulation: + bed load mobility reestablished

Atmospheric regulation: 0

Water quality regulation: + natural purification processes get increased, stretches without current get fewer

Pedogenesis and soil quality regulation: 0 (if hyporheic interstitial is included, positive effects due to restoration)

Lifecycle maintenance, habitat and gene pool protection: + improved habitat conditions for aquatic organisms (mainly due to increase of longitudinal connectivity)

Pest and disease control (incl. invasive alien species): +/- increase of naturalness of conditions, but improved migration pathways for invasives

Aesthetic, Heritage: +/- reestablishment of natural conditions, but weirs might be partly valuable heritage

Spiritual: + increase of naturalness and wilderness

Recreation and community activities: +/- accessability options decreased; naturalness increased (therefore also attractiveness for recreational use)

Information & knowledge: 0

27) Lateral floodplain reconnection measures

Terrestrial plants and animals for food: 0

Freshwater plants and animals for food: + better conditions for fish spawning

Water for human consumption: + probably at least some positive effects related to increased ground water level

Water for agricultural use: + probably at least some positive effects related to increased ground water level

Water for industrial and energy uses: + probably at least some positive effects related to increased ground water level

Biotic materials: +/- abundance of biotic materials will decrease and be less accessible, but diversity (incl. genetic diversity) of biotic materials will increase

Biomass based energy: - conditions for most bioenergy crops (e.g. Populus; energy crops(?)) will become worse or less stable

Bioremediation: + recovery of natural dynamics

Dilution and sequestration: + mostly positive because retention area is much bigger and because water gets more filtered if natural dynamics prevail

Air flow regulation: 0

Water flow regulation: + increase of retention capacity and natural dynamics

Mass flow regulation: + increase of natural erosion dynamics and related large scale natural erosion equilibrium (at local scale it might happen that negative erosion effects occur, but natural erosion equilibrium is the best solution)

Atmospheric regulation: + local climate regulation improved by keeping humidity in the floodplain

Water quality regulation: + improved filtration capacity

Pedogenesis and soil quality regulation: +/- improved natural dynamics, but pedogenesis at margins of side channels and oxbows is reduced

Lifecycle maintenance, habitat and gene pool protection: + natural habitat area and diversity increases, natural processes get restored

Pest and disease control (incl. invasive alien species): + increase of natural dynamics including natural pest control, (contribution to large-scale spread of IAS probably not significant)

Aesthetic, Heritage: + increase of outstanding natural beauty

Spiritual: + increased naturalness and wilderness

Recreation and community activities: - reduced accessability

Information & knowledge: + important for education and wildlife restoration programmes

28) Channel, oxbow and pond creation

Terrestrial plants and animals for food: - loss of area

Freshwater plants and animals for food: + increase of aquatic habitats

Water for human consumption: + increased ground water refill

Water for agricultural use: + increased ground water refill

Water for industrial and energy uses: + increased ground water refill

Biotic materials: +/- genetic ressources, less area for timber

Biomass based energy: - less area for wood fuel

Bioremediation: + increased bioremediation due to improved aquatic quality and larger active floodplain

Dilution and sequestration: + more retention --> less erosion; less carbon emissison

Air flow regulation: 0

Water flow regulation: + increase of retention and discharge capacity

Mass flow regulation: + probably more "regulated" due to larger retention area, less depth erosion due to increased discharge capacity for channel and oxbow

Atmospheric regulation: + improved due to wetter conditions that minimize carbon mineralisation

Water quality regulation: + more ponds, oxbows

Pedogenesis and soil quality regulation: + delivers sediments into the floodplain, more floodplain dynamic -> creates natural conditions

Lifecycle maintenance, habitat and gene pool protection: + natural habitat area and diversity increases

Pest and disease control (incl. invasive alien species): (- short term effects by construction might be negative)

Aesthetic, Heritage: + increase of outstanding natural beauty

Spiritual: + increase of wilderness

Recreation and community activities: + increased wildernesss, more attractive

Information & knowledge: + more wilderness

29) Construction of fish passages

Terrestrial plants and animals for food: 0

Freshwater plants and animals for food: + more fish can pass the river

Water for human consumption: 0

Water for agricultural use: 0

Water for industrial and energy uses: 0

Biotic materials: + for genetic ressources

Biomass based energy: 0

Bioremediation: 0

Dilution and sequestration: 0

Air flow regulation: 0

Water flow regulation: 0

Mass flow regulation: 0 (+future facilities might tackel the debris better)

Atmospheric regulation: 0

Water quality regulation: 0

Pedogenesis and soil quality regulation: 0

Lifecycle maintenance, habitat and gene pool protection: + improved longitudinal connectivity for aquatic organisms

Pest and disease control (incl. invasive alien species): - maybe invasives get easier upstreams and downstreams

Aesthetic, Heritage: 0

Spiritual: 0

Recreation and community activities: + if natural fish populations recover, it might have positive effects on recreational fishing

Information & knowledge: 0

30) Creation of natural habitat by transforming forest plantations

Terrestrial plants and animals for food: + to be expected at least small possitive effects on diversity and abundance of wild plants and animals (such as fungi, berry, game, honey)

Freshwater plants and animals for food: + to be expected at least small possitive effects on diversity and abundance of fish

Water for human consumption: + possitive effects on groundwater refill, additionally decrease of demand of water

Water for agricultural use: + possitive effects on groundwater refill, additionally decrease of demand of water

Water for industrial and energy uses: + possitive effects on groundwater refill, additionally decrease of demand of water

Biotic materials: +/- timber gets reduced, rest gets more

Biomass based energy: - wood fuel decline

Bioremediation: + natural processes get restored and reactivated

Dilution and sequestration: +/- sequestration might decrease, dilution might increase

Air flow regulation: 0

Water flow regulation: + increase of dynamics of natural water flow

Mass flow regulation: + increase of natural mass flow dynamics (erosion and sedimentation)

Atmospheric regulation: 0

Water quality regulation: + natural processes get reactivated, enrichment with oxygen

Pedogenesis and soil quality regulation: + natural processes increase, natural soil generation increases

Lifecycle maintenance, habitat and gene pool protection: + natural habitat area and diversity increases, natural processes get restored

Pest and disease control (incl. invasive alien species): + pest control capacity is probably higher in natural floodplains (as diversity of habitats and species is increased)

Aesthetic, Heritage: + increase of aestetic values

Spiritual: + increase of wilderness

Recreation and community activities: -/+ landscape character and beauty are increased, accessability/usability is decreased

Information & knowledge: + important for education and wildlife restoration programmes

31) Creation of natural habitat by transforming agricultural land

Terrestrial plants and animals for food: - agricultural land was more productive

Freshwater plants and animals for food: + possitive effects on diversity and abundance of fish

Water for human consumption: + possitive effects on groundwater refill, additionally decrease of demand of water and decrease of pollution

Water for agricultural use: + possitive effects on groundwater refill, additionally decrease of demand of water

Water for industrial and energy uses: + possitive effects on groundwater refill, additionally decrease of demand of water

Biotic materials: +/- straw gets reduced, other biotic materials get more

Biomass based energy: - energy crops decline

Bioremediation: + natural processes get restored and reactivated

Dilution and sequestration: + natural processes get restored and reactivated

Air flow regulation: + increase of moist/wet area, increase of vegetation cover

Water flow regulation: + increase of dynamics of natural water flow

Mass flow regulation: + increase of natural mass flow dynamics (erosion and sedimentation)

Atmospheric regulation: + increase of moist/wet area, increase of vegetation cover

Water quality regulation: + natural processes get reactivated, enrichment with oxygen

Pedogenesis and soil quality regulation: + natural processes increase, natural soil generation increases

Lifecycle maintenance, habitat and gene pool protection: + natural habitat area and diversity increases, natural processes get restored

Pest and disease control (incl. invasive alien species): + pest control capacity is high in natural floodplains (habitat for natural pest control organisms)

Aesthetic, Heritage: + increase of aestetic values (although specific agricultural use might be an important cultural heritage)

Spiritual: + increase of wilderness

Recreation and community activities: -/+ landscape character and beauty are increased, accessability/usability is decreased

Information & knowledge: + important for education and wildlife restoration programmes

32) Creation of natural habitat by transforming extraction sites

Terrestrial plants and animals for food: + possitive effects on diversity and abundance of wild plants and animals (such as fungi, berry, game, honey)

Freshwater plants and animals for food: + possitive effects on diversity and abundance of fish

Water for human consumption: + possitive effects on groundwater refill, additionally decrease of demand of water and decrease of pollution

Water for agricultural use: + possitive effects on groundwater refill, additionally decrease of demand of water

Water for industrial and energy uses: + positive effects on groundwater refill, additionally decrease of demand of water

Biotic materials: + more products from natural floodplain

Biomass based energy: + fire wood increase

Bioremediation: + natural processes get restored and reactivated

Dilution and sequestration: + natural processes get restored and reactivated

Air flow regulation: + increase of moist/wet area, increase of vegetation cover

Water flow regulation: + increase of dynamics of natural water flow

Mass flow regulation: + increase of natural mass flow dynamics (erosion and sedimentation)

Atmospheric regulation: + increase of moist/wet area, increase of vegetation cover

Water quality regulation: + natural processes get reactivated, enrichment with oxygen

Pedogenesis and soil quality regulation: + natural processes increase, natural soil generation increases

Lifecycle maintenance, habitat and gene pool protection: + natural habitat area and diversity increases, natural processes get restored

Pest and disease control (incl. invasive alien species): + pest control capacity is high in natural floodplains (habitat for natural pest control organisms)

Aesthetic, Heritage: + increase of aestetic values

Spiritual: + increase of wilderness

Recreation and community activities: -/+ landscape character and beauty are increased, accessability/usability is decreased

Information & knowledge: + important for education and wildlife restoration programmes

33) Control of invasive alien species

Terrestrial plants and animals for food: + potential positive effects due to increased potential for agri- / silvicultural use, higher yields; improved conditions for edible wild fruit plants etc.

Freshwater plants and animals for food: + potential positive effects due to improved conditions for edible aquatic species (fish, crayfish), eventual temporal loss due to eradication of non-native fish, should be rapidly recovered by increasing native spp. populations

Water for human consumption: - biocide would cause pollution

Water for agricultural use: 0

Water for industrial and energy uses: 0

Biotic materials: +/- potential positive effects on provision of biotic materials, but some very productive spp. (e.g timber hybrid poplar) are aliens and will be reduced

Biomass based energy: +/- potential positive effects on provision of biomass based energy, but some very productive spp. (e.g timber hybrid poplar) are aliens and will be reduced

Bioremediation: + natural processes get restored and reactivated

Dilution and sequestration: +/- natural processes may get restored and reactivated, but this depends strongly on the sitaution and the type of measure. Also negative effects may occur, e.g. when biocides are applied

Air flow regulation: 0

Water flow regulation: + water flow might have been effected by IAS, control leads to renaturalization of water flow

Mass flow regulation: + mass flow might have been effected by IAS, control leads to renaturalization of water flow

Atmospheric regulation: 0

Water quality regulation: 0

Pedogenesis and soil quality regulation: + potential positive effects if removed alien plant species had negative effects on soil properties

Lifecycle maintenance, habitat and gene pool protection: + improved habitat conditions, natural processes get restored

Pest and disease control (incl. invasive alien species): + removal of alien species

Aesthetic, Heritage: +/- increase of natural beauty and aesthetic value (but partly opposite effects on aestetic due to eradication of ornamental alien plants)

Spiritual: + increase of naturalness and wilderness

Recreation and community activities: + higher recreational value of floodplain without too many IAS

Information & knowledge: + awareness raising is an important issue for the mitigation of invasions

34) Sediment addition

Terrestrial plants and animals for food: 0

Freshwater plants and animals for food: + improved spawning and habitat conditions for fish

Water for human consumption: 0

Water for agricultural use: 0

Water for industrial and energy uses: 0

Biotic materials: 0

Biomass based energy: 0

Bioremediation: + recovery of natural succession and related processes and dynamics

Dilution and sequestration: 0

Air flow regulation: 0

Water flow regulation: 0

Mass flow regulation: + more natural and stronger erosion dynamics (at least when done in a meaningful combination of measures)

Atmospheric regulation: 0

Water quality regulation: 0

Pedogenesis and soil quality regulation: + can lead to initialization of pedogenesis

Lifecycle maintenance, habitat and gene pool protection: + improved habitat conditions for many species

Pest and disease control (incl. invasive alien species): - alien species might settle on new sediments, which are also good corridors for alien species migration

Aesthetic, Heritage: 0

Spiritual: + positive for wilderness/naturalness of floodplain

Recreation and community activities: + good recreation option

Information & knowledge: + potentially positive for educational purposes

35) Elimination of top soil

Terrestrial plants and animals for food: - potentially elimination of habitats for geophytes and fungi growing in or on the soil

Freshwater plants and animals for food: 0

Water for human consumption: - potentially negative effects due to missing filter capacity of top soil

Water for agricultural use: 0

Water for industrial and energy uses: 0

Biotic materials: - temporare loss of habitat for timber, genetical ressources, etc.

Biomass based energy: - temporare loss of habitat for biofuels and energy crops

Bioremediation: - temporal loss of vegetation and soil (including rhizosphere), later natural processes will recover

Dilution and sequestration: - loss of vegetation and soil (rhizosphere)

Air flow regulation: 0

Water flow regulation: + improved dynamics and vertical hydrological connectivity

Mass flow regulation: + increased natural dynamics

Atmospheric regulation: - decrease of evapotranspiration

Water quality regulation: + improved dynamics and vertical hydrological connectivity

Pedogenesis and soil quality regulation: +/- elimination of "contaminated" agricultural soils, but negative effects as due to soil and vegetation disapearance; pedogenesis gets reduced

Lifecycle maintenance, habitat and gene pool protection: + natural habitat area and diversity increases, natural processes get restored

Pest and disease control (incl. invasive alien species): +/- possitive effects due to the removal of seed banks which causes a decrease of invasive alien species and enables improved competitive conditions for local pioneer species, but depending on propagule pressure the restored areas might become heavily invased by IAS

Aesthetic, Heritage: - (at least short-midterm) reduced aesthetics

Spiritual: 0

Recreation and community activities: 0

Information & knowledge: +/- enables research on succession (but somehow loss of information due to removal) and enhances education (but complicated issues and might be problematic for attitude towards nature conservation)

36) Land use extensification

Terrestrial plants and animals for food: - reduced productivity through extensification of agriculture and hunting

Freshwater plants and animals for food: +/- overall positive effects, but extensification of fishery might have negative effects

Water for human consumption: + less water pollution due to reduction of fertilizers

Water for agricultural use: 0

Water for industrial and energy uses: 0

Biotic materials: +/- reduction in abundance, increase of diversity of biotic materials

Biomass based energy: - reduced productivity of biofuels and energy crops

Bioremediation: + higher diversity in land use and less chemical and mechanical disturbance; thus, natural processes get restored and reactivated

Dilution and sequestration: + lower level of nutrients and pollutants implies better sequestration/take off capacity

Air flow regulation: 0

Water flow regulation: 0

Mass flow regulation: - recovery towards natural mass flow dynamics

Atmospheric regulation: + positive due to reduction of life stock and due to reduction of traffic related to intensive land use

Water quality regulation: + less water pollution due to reduction of fertilizers

Pedogenesis and soil quality regulation: + less disturbance and less biomass uptake

Lifecycle maintenance, habitat and gene pool protection: + less disturbance, improved habitat conditions, natural processes can recover

Pest and disease control (incl. invasive alien species): + improved biocontrol due to more diverse land use

Aesthetic, Heritage: + recreation of traditional cultural landscapes

Spiritual: 0

Recreation and community activities: + optimal recreation conditions

Information & knowledge: + good show case for wise land use

37) Establishment, maintenance and usage of recreational infrastructure

Terrestrial plants and animals for food: 0

Freshwater plants and animals for food: 0

Water for human consumption: 0

Water for agricultural use: 0

Water for industrial and energy uses: 0

Biotic materials: 0

Biomass based energy: 0

Bioremediation: 0

Dilution and sequestration: 0

Air flow regulation: 0

Water flow regulation: 0

Mass flow regulation: 0

Atmospheric regulation: 0

Water quality regulation: 0

Pedogenesis and soil quality regulation: 0

Lifecycle maintenance, habitat and gene pool protection: - natural habitat gets destroyed

Pest and disease control (incl. invasive alien species): - alien species settle on artificial habitats created by constructions, which are also good corridors for alien species migration

Aesthetic, Heritage: -/+ negative effects of artificial constructions on aestetics; eventually positive for conservation of local heritage

Spiritual: - decrease of wilderness and tranquility

Recreation and community activities: + increase of recreation options and accessability

Information & knowledge: + nowadays thes should be built without destroying much nature, positive effects on education etc. should clearly be much stronger

38) Recreational use of the floodplain

Terrestrial plants and animals for food: 0 collecting activities are not intensive enough to negatively affect the supply of the ESS

Freshwater plants and animals for food: 0 fishing activities are not intensive enough to negatively affect the supply of the ESS

Water for human consumption: 0

Water for agricultural use: 0

Water for industrial and energy uses: 0

Biotic materials: 0

Biomass based energy: 0

Bioremediation: 0

Dilution and sequestration: 0

Air flow regulation: 0

Water flow regulation: 0

Mass flow regulation: 0

Atmospheric regulation: 0

Water quality regulation: 0

Pedogenesis and soil quality regulation: 0

Lifecycle maintenance, habitat and gene pool protection: - disturbance of nursary habitats of sensitive species, eventually harvest of specific species

Pest and disease control (incl. invasive alien species): 0 eventually marginal effects due to people who release alien species

Aesthetic, Heritage: 0

Spiritual: 0

Recreation and community activities: + additional options for recreation

I**nformation & knowledge:** 0

Annex C.4 – A preliminary systematic map on the impact of floodplain management on biodiversity in temperate regions

(cf. Chapter 6.3.4)

Title: Impact of floodplain management on biodiversity in temperate regions: a preliminary systematic map.

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Abstract

The search for literature on the topic impact of floodplain management on biodiversity in temperate regions resulted in 4131 hits in the databases Scopus and Thompson Reuters Web of Knowledge. After we screened the titles regarding the inclusion criteria specified in the systematic review protocol, 3640 papers were excluded from the study and 491 remained. By viewing the abstracts and, in a next step, the titles of the remaining articles, further 421 papers were excluded and 70 papers could finally be included in this preliminary version of the systematic map. Many of the papers excluded did not complete with the inclusion criteria, because we could not evaluate the river order, which had to be >3 to be included. 31 journals served as sources regarding the selected articles, and “River Research and Applications” was the journal with the highest number of. Most of the articles were published during the last five years, emphasising the actuality and relevance of the topic. The majority of the study regions of the articles were located in the US, followed by Germany and France and we identified a focus on studies related to restoration (especially reconnection) and production activities (e.g. construction of hydropower plants). Arthropods were the most commonly studied organisms, followed by fish and birds. Totally 67 analyses were performed for zoological taxa, 17 for plants and 2 for bacteria. More than half of the articles presented studies using a C-I (Control-Impact) study design, followed by B-A (Before-After) studies. 13 out of 70 articles presented studies based on a B-A-C-I (Before-After-Control-Impact) study design. Many of the articles did not provide any information about the time between the interventions took place and data sampling, which must be considered as quality drawback. 22 of the included studies presented in the articles were carried out shortly after the intervention took place (0-2 years). Only a few studies evaluated long-term effects of different interventions, which should be a focus of future investigations.

Preliminary Systematic Map – Full text:

The search for literature on the topic multifunctional floodplain management in Europe resulted in 4131 hits in the databases Scopus and Thompson Reuters Web of Knowledge. After we screened the titles regarding the inclusion criteria specified in the systematic review protocol (Schindler et al. 2013; see Chapter 6.3.1), 3640 papers were excluded from the study and 491 remained. By viewing the abstracts of the remaining papers and applying defined inclusion criteria 151 further articles were excluded from the study. A total of 340 articles remained and after screening the full text, 70 papers could finally be included in the systematic map and the systematic review process (Figure 1). Many of the paper rejected at this stage did not specify the Strahler´s River order, whereas it was one of the inclusion criteria that this number must be >3 (Schindler et al. 2013; see Chapter 6.3.1 & Annex C.1).

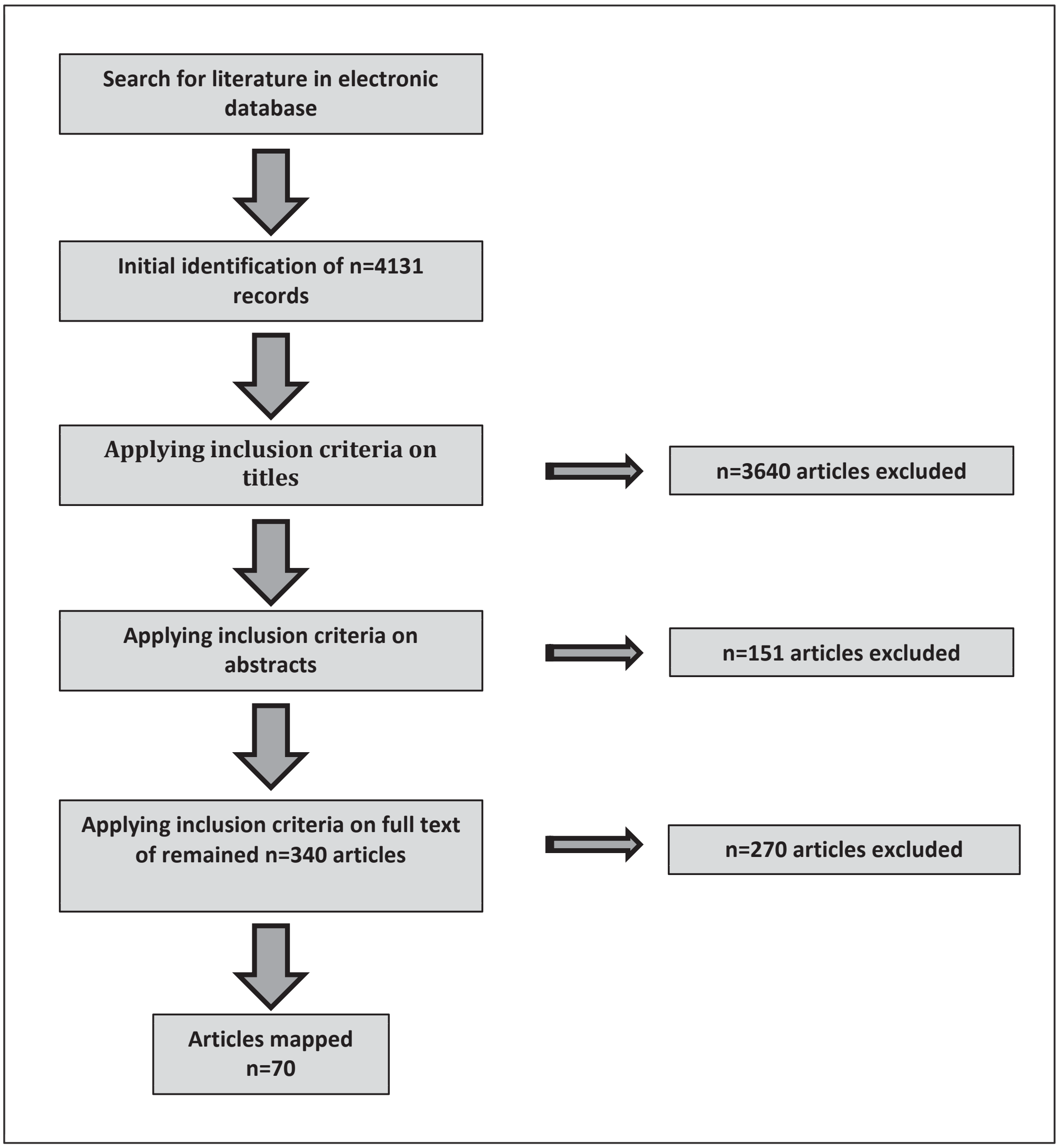

Figure 2. Articles included and excluded at different stages of the review and mapping process.

Journals publishing relevant articles

31 journals served as sources regarding the selected articles (Figure 2). In total, 26% of the articles were published in the journal "River Research and Applications" (n=14) and it's predecessor "Regulated Rivers-Research and Applications" (n=4). Seven articles were published in the "Journal of Applied Ecology, followed by "Ecological Engineering" (n=6) and "Hydrobiologia" (n=5).

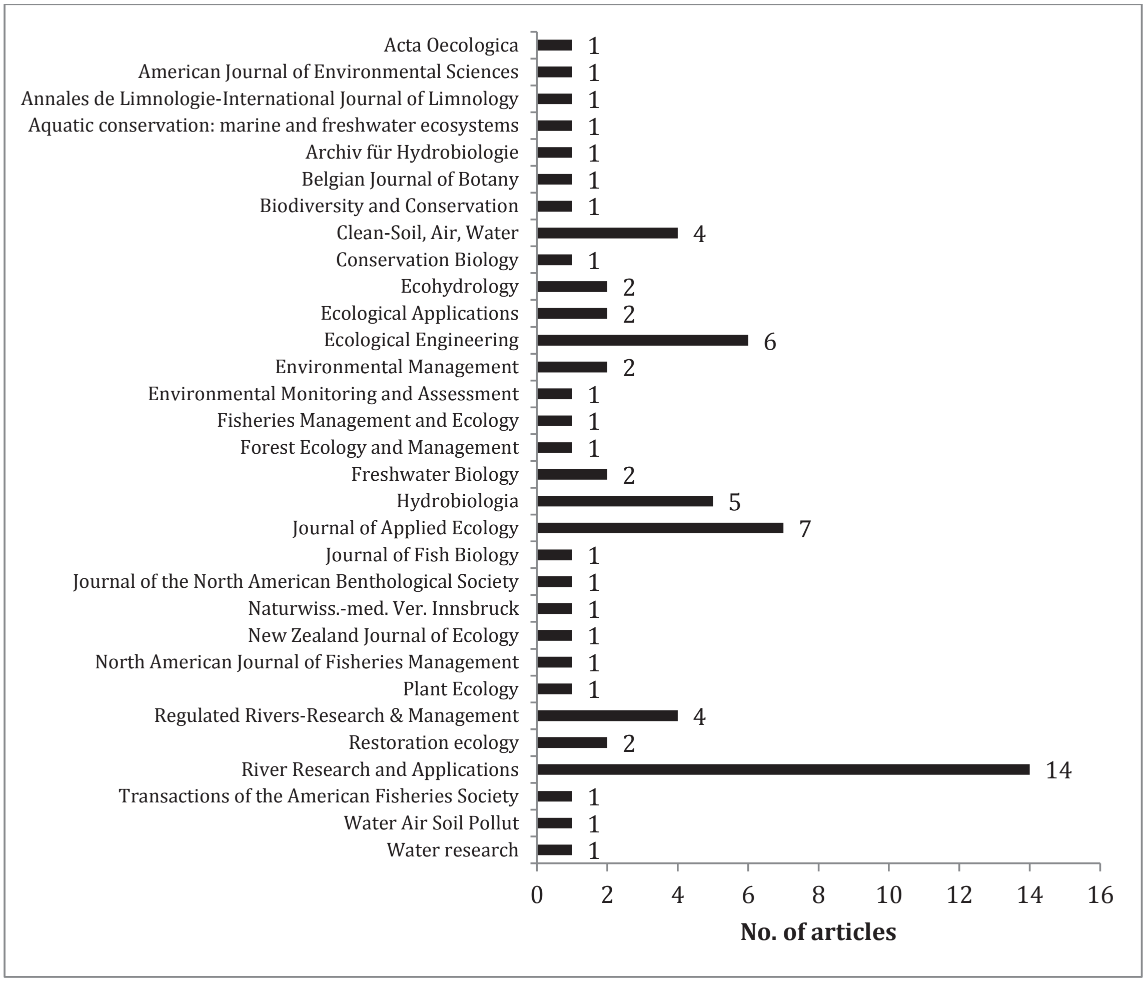

Figure 2. Journals where articles included into the systematic map were published.

Year of publication

Most of the included articles were published in recent years (Figure 3), and more than half of the included papers were published in the last five years emphasising the actuality and relevance of the topic. The earliest article was published in 1991 followed by a slow increase of publications in the 90's and a rather strong increase since 2006. The low number of articles in 2013 can be traced back to the implementation of the systematic mapping process at the beginning of 2013.

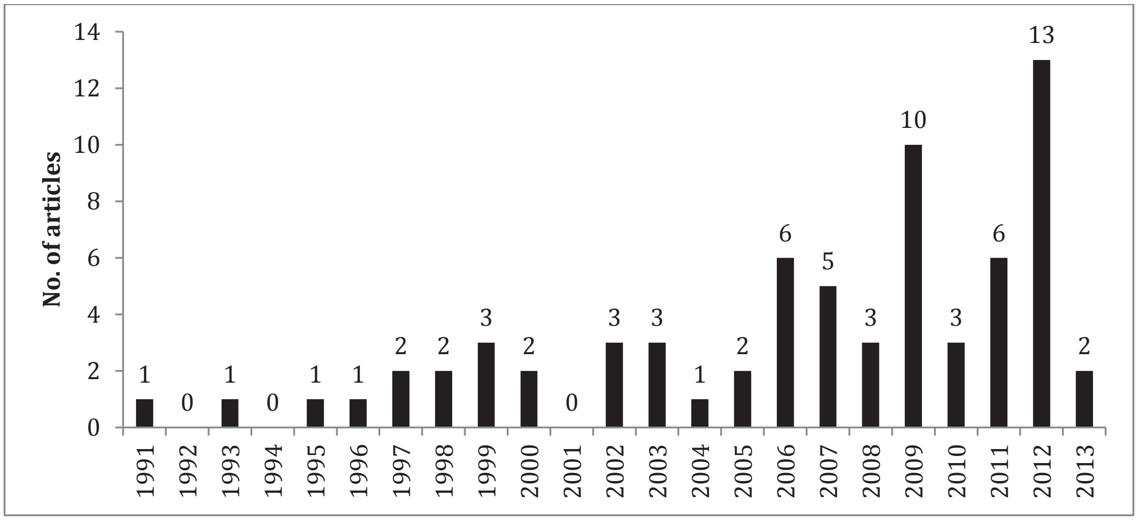

Figure 3. Number of articles published each year.

Study regions

26% of the study regions of the articles were located in the US, followed by European countries (in total 70%), especially Germany and France (Figure 3). Only a few studies were carried out in Mediterranean countries, whilst there were several studies originating from central or northern Europe.

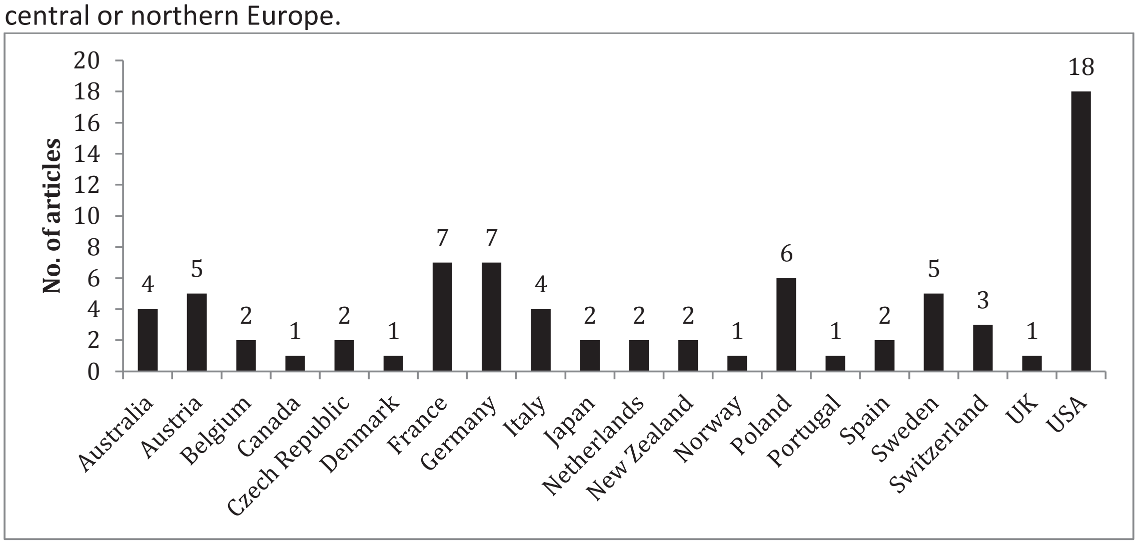

Figure 4. Number of articles published in different countries

Floodplain interventions assessed in articles

Most of the articles considered interventions focusing on restoring the connectivity of the floodplain ecosystem, especially on dam removal (which enhances longitudinal connectivity of the river) and lateral floodplain reconnection measures (Table 1). Whereas we found several articles regarding restoration- and production related interventions (including e.g. construction of hydropower plants), the search resulted in only few articles (n=3) evaluating the impact of different land use schemes on the biodiversity of floodplain ecosystems.

Table 3. Number of articles related to each bundle of intervention and each specific intervention. (see Chapter 6.3.3. & Annex C.3 for detailed information on the interventions).

Interventions	No. of articles	Interventions	No. of articles
Production – extraction	**11**	***Hydrological engineering - rehabilitation***	**7**
Surface water extraction	5	Dike relocation	1
Groundwater extraction		Ecologically improved groynes	1
Mineral resource extraction	1	Lowering floodplain/foreland	2
Others	5	Sediment addition	
Production – infrastructure	**11**	Removing obstacles	
Terrestrial settlement and traffic infrastructure [except dikes, etc.]		Others	3
Energy conversion	6	***Restauration - connectivity***	**23**
Navigational infrastructure		Removal of bank fixations	2
Others	5	Removal of dams and weirs	6
Production – intensive land use	**1**	Lateral floodplain reconnection measures	7
Forestry intensive	1	Channel, oxbow and pond creation	1
Agriculture intensive		Construction of fish passages	1
Fishery intensive		Others	6
Production – extensive land use	**2**	***Restauration - renaturation***	**15**
Forestry extensive		Creation of natural habitat by transforming forest plantations	
Agriculture extensive	2	Creation of natural habitat by transforming agricultural land	
Fishery extensive		Creation of natural habitat by transforming extraction sites	1
Hunting		Control of invasive alien species	2
Hydrological engineering - regulation	**5**	Creation of gravel banks	1
Channel corrections	3	Removal of top soil	
Dike construction		Land use extensification	
Bank/bed stabilization	1	Others	11
Sediment removal/dredging	1	***Recreation***	**0**
Detention basins		Establishment, maintenance and usage of recreational infrastructure	
Controlled retention areas		Recreational use of the floodplain	

Groups of Organisms

Arthropods, especially macroinvertebrates, were the most commonly studied organisms (n=33), followed by fish (n=18) and birds (n=9). Totally 67 analyses were performed for zoological taxa, 17 for plants and 2 for bacteria (Figure 4). Several papers contained analyses for more than one group of organisms.

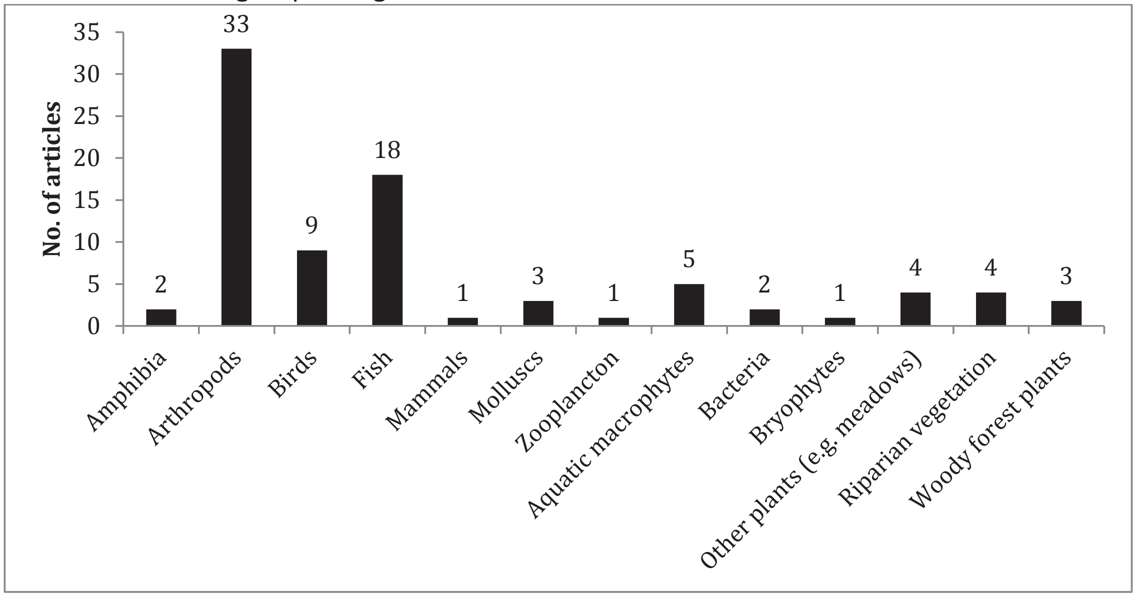

Figure 4. Number of analyses per taxon encountered in the 70 papers.

Study Design

More than half of the articles (n=41) presented studies using a C-I (Control-Impact) study design, followed by B-A (Before-After) studies (n=16). 13 out of 70 articles presented studies based on a B-A-C-I (Before-After-Control-Impact) study design (Figure 5), which is considered as most appropriate and powerful for impact assessments (Smith 2002; Schindler et al. 2013).

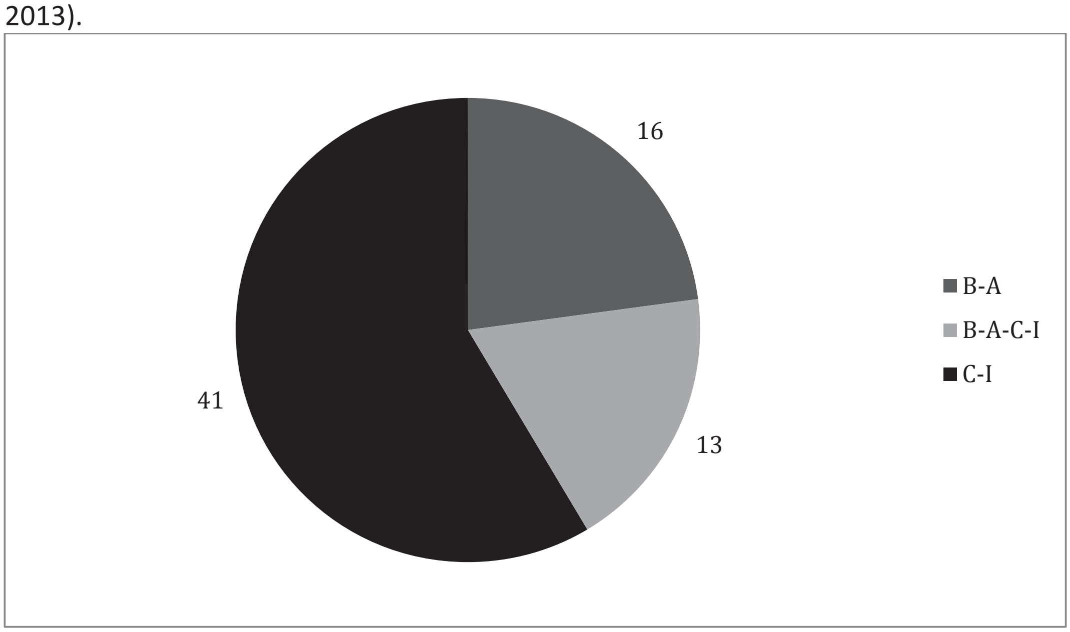

Figure 5. Number of articles reporting studies with B-A (Before-After), C-I (Comparator-Impact) or B-A-C-I (Before-After-Control-Impact)design.

Time since intervention

20% of the articles did not provide any information about the time between the interventions took place and data sampling (Figure 5). Because of the strong influence of this factor on results of biodiversity measures, missing information regards time since intervention must be considered as quality drawback. 22 of the included studies presented in the articles were carried out short after the intervention took place (0-2 years), which depending on the organisms under concern and the intervention might be too early for having reached a new equilibrium (Dullinger et al. 2013). Only a few studies evaluated long-term effects of different interventions, which should be a focus of future investigations, although data acquisition might cause difficulties.

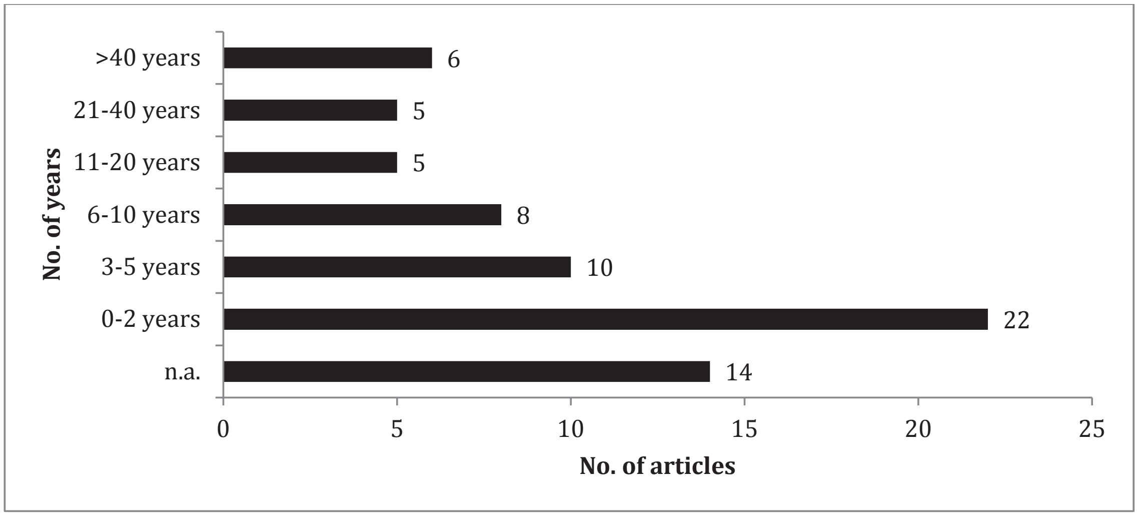

Figure 5. Number of articles reporting studies based on different designs regarding the time since intervention.

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