# State-of-the-art summary of ecosystem services

## Report

SEDECO (ATCZ 28)

T2.4.1

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**SEDECO (ATCZ 28)**

**Sedimente, Ökosystemdienstleistungen und Wechselwirkungen mit Hochwasser und Dürre in der AT-CZ Grenzregion**

**Sedimenty a ekosystémové služby ve vzájemném působení s povodněmi a suchem v pohraniční oblasti AT-CZ**

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# Report


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## Abstract

Ecosystem services (ES) are described as the benefits provided to humans by the natural environment and its ecosystems. People can benefit either directly or indirectly by the provision of other goods and services. Direct benefits are, for example, the provision of food products, drinking water or local recreation. Examples for indirect benefits include riparian wetlands, which on the one hand reduce flood risk through water retention and on the other hand act as retention space for pollutants.

The present study looked into the past development of different strategies for the assessment of ES. A comprehensive literature research was conducted to get an overview of the state-of-the-start approaches and of current challenges in respect of the assessment of ES. The present report also includes the results of the literature research on local and international case studies about the potential of restoration activities and its effects on ES.

With the Millennium Ecosystem Assessment (MEA), the United Nations conducted the first major study on the global state of 24 key-ES between 2001 and 2005. According to the MEA, which differentiates between provisioning, regulating, cultural and supporting services, 60 % of the ES are in an advanced degraded and/or ongoing degrading state. In 2007, the Economics of Ecosystems and Biodiversity (TEEB) initiative was started aiming to conduct an economic assessment of ES. The classification system of TEEB is based on the MEA but substitutes supporting services with habitat services. Another major classification system is called the Common International Classification of Ecosystem Services (CICES) and was first published in 2013. CICES distinguishes between provisioning services, regulation and maintenance services, and cultural services. This classification system does not aim to replace the ones mentioned before but to allow users to move more easily between them and to better understand the underlying processes. The literature review on case studies showed that several examples exist, which indicate the wide range of positive effects of river restoration on ES. These case studies illustrated the high potential of how ecosystems can profit from restoration measures at rivers and therefore, highlight the need to increase the number of such restoration measures.

## Contents

# 1 Introduction

Ecosystem services (ES) have been discussed as early as the 1970s, however, the concept gained importance with the Millennium Ecosystem Assessment (MEA). The MEA was conducted from 2001 to 2005 under the auspices of the United Nations. Its main aim was to establish a scientific basis for the sustainable use of ecosystems and to assess the consequences of their changes for human well-being. Further aims were to assess measures to conserve ecosystems. It was concluded that ecosystems are highly valuable resources and significantly support human well-being. However, most of ES are used unsustainably and are currently being degraded, which poses an urgent threat for future generations. A follow-up study to the MEA was the Economics of Ecosystems and Biodiversity (TEEB) project, which aimed to assign an economic value to ES and to provide tools for their assessment. In addition, several studies have worked on classifying ES systematically to aid research efforts and decision making (e.g. the Common International Classification of Ecosystem Services - CICES). The present report has been developed within the Interreg project SEDECO and aims to summarise the state-of-the art as well as national and international case studies in connection with ES. Based on the existing case studies, the potential of restoration efforts on riverine ES are presented (Millennium Ecosystem Assessment, 2005; TEEB, 2008; de Groot et al., 2010).

## 1.1 Definition of ecosystem services

ES are defined as the benefits people obtain from ecosystems (Millennium Ecosystem Assessment, 2005). ES can be divided into direct and indirect benefits. Examples for direct benefits include food, water, climate regulation and recreation while an indirect benefit is, for instance, the ability of riparian wetlands to retain pollutants in the soil and vegetation. Riparian wetlands also act a retention space during flood events and thus, benefit flood protection. It is recognised that humanity is fundamentally dependent on ES; therefore, urgent actions are needed to protect and conserve them for this and future generations. When discussing ecosystems, a distinction needs to be made between ES and ecosystem functions. The growing scientific consensus regards ES as final benefits humans derive from ecosystems directly and indirectly. Consequently, ecosystem functions are understood as intermediates leading to the final services (Figure 1). Ecosystem processes are understood as the underlying principles, structures and processes enabling ecosystem functions and services (de Groot et al., 2010).

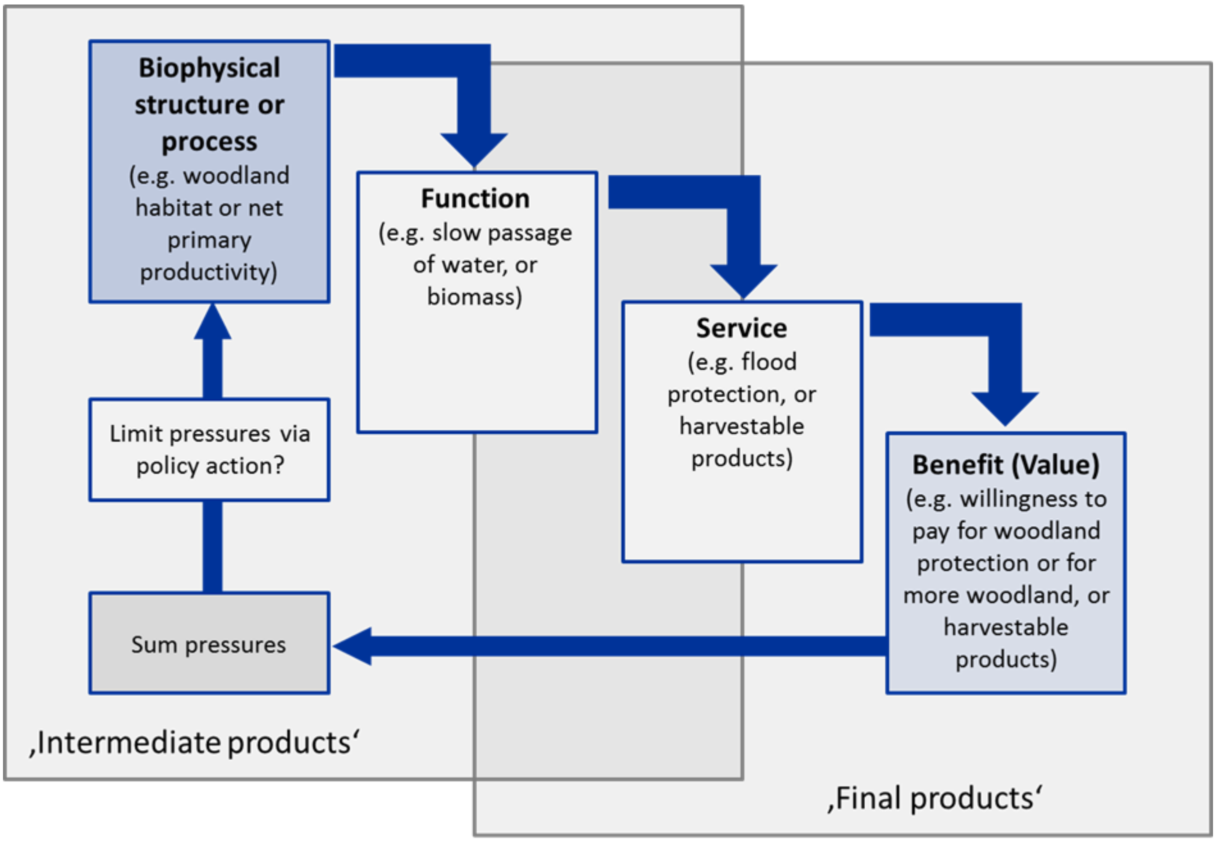


*Figure 1: Cascade model describing the relationship between biodiversity, ecosystem function and human well-being (modified after Haines-Young and Potschin, 2010).*

## 1.2 Classification systems of ecosystem services

In order to discuss and assess ES effectively, a classification system needs to be developed. Several studies and initiatives have worked towards such a classification system and are described below.

### 1.2.1 The Millennium Ecosystem Assessment (MEA)

In year 2001, the United Nations initiated the MEA, which involved more than 1,360 scientists worldwide to contribute to the elaboration of this classification system. One of the main objectives was to analyse the current status and trend of ES. Moreover, the MEA aimed to highlight sustainable possibilities for the restoration or conservation of ES. The results of this study were summarized in five technical volumes and six synthesis reports (Millennium Ecosystem Assessment, 2005). The study showed that out of 24 ES assessed, 15 are in a degraded state (Schwaiger et al., 2015). The results of the MEA contributed to a more intense public discussion of ES leading to several studies dealing with this topic (e.g. Grünigen et al., 2013; Jacobs et al., 2014; Dehnhardt, 2014; Meyerhoff et al., 2014). In addition, several subsequent classification systems used the MEA as basis for the development of assessment strategies (Schwaiger et al., 2015).

The MEA distinguishes four different classes of ES, which are provisioning, regulating, cultural and supporting (Figure 2). Provisioning services include food, water, timber or fibre; regulating services influence climate, floods or diseases. Examples for cultural services include the recreational, aesthetic and spiritual effects of ecosystems; and supporting services describe processes such as photosynthesis and nutrient cycling (Millennium Ecosystem Assessment, 2005).

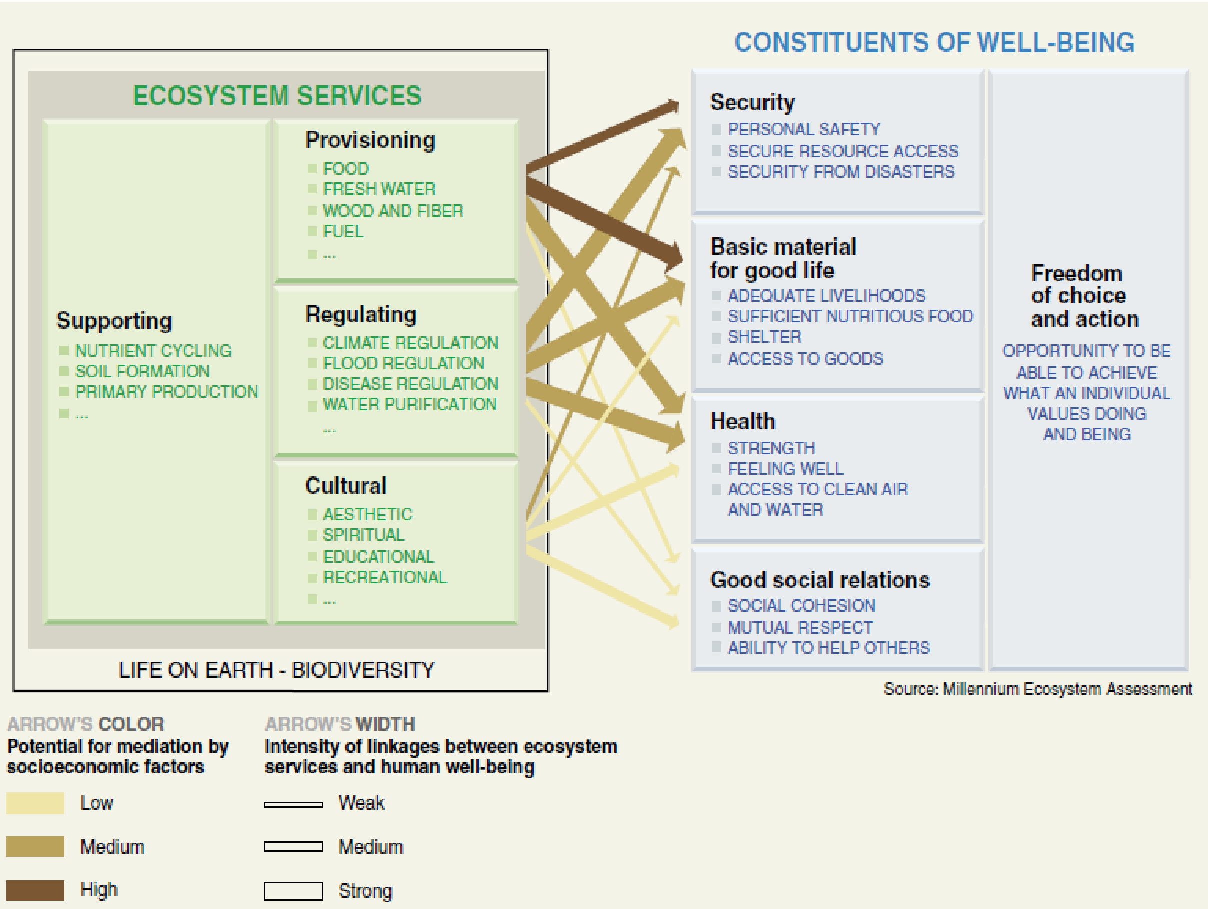


*Figure 2: Links between ES and human well-being (Millennium Ecosystem Assessment, 2005).*

### 1.2.2 The Economics of Ecosystems and Biodiversity (TEEB)

The TEEB is a research initiative that was started in 2007 by the environment ministers of the G8+5 member states. The main objective of this global initiative is to study the loss of biodiversity and its functions by assigning economic values to ES (European Commission, 2022). By capturing the values of ES and biodiversity, the TEEB initiative further aims to show policymakers the benefits of nature conservation and the consequences of its degradation in order to protect the natural environment more efficiently (Schröter-Schlaack, 2014).

TEEB consists of three phases. The first phase was presented as an interim report in 2008. This report already showed that the economic value of ES for people is considerably higher than economics and scientists' estimation so far. The approx. 100,000 protected areas worldwide provide ES for human society worth USD 4,400 – 5,200 billion a year (TEEB, 2008). The second phase involved the elaboration of single reports for different stakeholders. Starting in 2009, the first report was written for national and international political decision-makers, followed by reports for companies, and local and regional decision-makers. The final TEEB report was presented at the 10th Convention on Biological Diversity (CBD) in Japan (BMUV, 2016). The third phase involves the implementation of TEEB at national level. In Germany, for example, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) implemented the TEEB concept with the project "Naturkapital Deutschland - TEEB DE" (BMUV, 2016).

The classification system of TEEB concept was mostly adopted from the MEA with the following deviations. TEEB proposed a distinction of 22 ES divided into four main categories: provisioning services, regulating services, habitat services and cultural & amenity services (Table 1). The main difference to the MEA classification system is the omission of the category supporting services, which was substituted by habitat services. Habitat services describe the potential of ecosystem to provide habitat for migratory species and to protect gene-pools (TEEB, 2010).

*Table 1: ES classification adopted by the TEEB project (TEEB, 2010).*

| | **MAIN SERVICE TYPES** |
|---|---|
| | **PROVISIONING SERVICES** |
| 1 | Food (e.g. fish, game, fruit) |
| 2 | Water (e.g. for drinking, irrigation, cooling) |
| 3 | Raw Materials (e.g. fiber, timber, fuel wood, fodder, fertilizer) |
| 4 | Genetic resources (e.g. for crop-improvement and medicinal purposes) |
| 5 | Medicinal resources (e.g. biochemical products, models & test-organisms) |
| 6 | Ornamental resources (e.g. artisan work, décorative plants, pet animals, fashion) |
| | **REGULATING SERVICES** |
| 7 | Air quality regulation (e.g. capturing (fine)dust, chemicals, etc) |
| 8 | Climate regulation (incl. C-sequestration, influence of vegetation on rainfall, etc.) |
| 9 | Moderation of extreme events (eg. storm protection and flood prevention) |
| 10 | Regulation of water flows (e.g. natural drainage, irrigation and drought prevention) |
| 11 | Waste treatment (especially water purification) |
| 12 | Erosion prevention |
| 13 | Maintenance of soil fertility (incl. soil formation) |
| 14 | Pollination |
| 15 | Biological control (e.g. seed dispersal, pest and disease control) |
| | **HABITAT SERVICES** |
| 16 | Maintenance of life cycles of migratory species (incl. nursery service) |
| 17 | Maintenance of genetic diversity (especially in gene pool protection) |
| | **CULTURAL & AMENITY SERVICES** |
| 18 | Aesthetic information |
| 19 | Opportunities for recreation & tourism |
| 20 | Inspiration for culture, art and design |

| | |
|---|---|
| 21 | Spiritual experience |
| 22 | Information for cognitive development |

### 1.2.3 The Common International Classification of Ecosystem Services (CICES)

In 2009, the European Environment Agency (EEA) started working on the Common International Classification of Ecosystem Services (CICES), which was finally published in 2013. After a review process based on experiences by users, the revised version was released in 2018. Since the first publication of CICES, this classification system was widely used for ecosystem mapping and assessment. Figure 3 shows the cascade model, in which the CICES concept is applied. CICES focuses on the final ES, which are provided to the human society by ecosystems and benefit people in the most direct way (Haines-Young and Potschin, 2018).

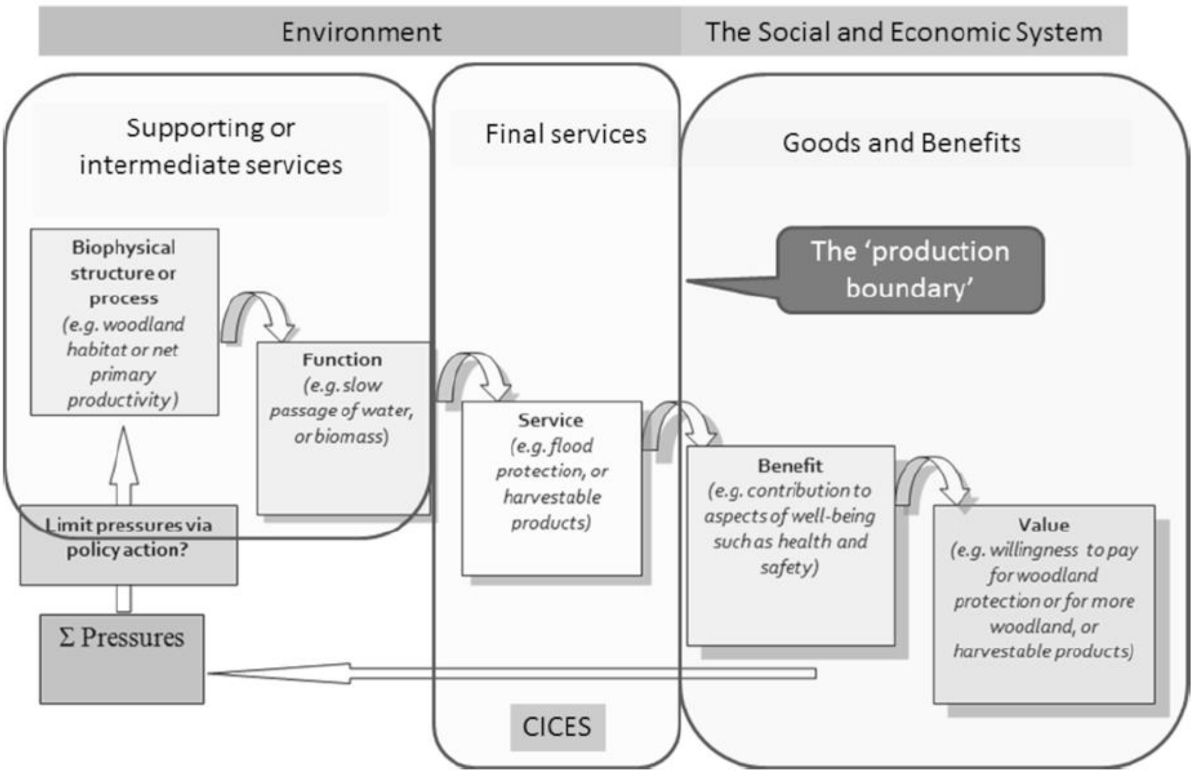


*Figure 3: The cascade model of the CICES concept (Potschin and Haines-Young, 2016).*

The aim of CICES was to develop a classification system that could link existing systems and enable people to move more easily between them. CICES distinguishes between three sections of services: provisioning services, regulation and maintenance services and cultural services. The category "supporting services" defined by the MEA is not recognised. The three main sections are then subdivided into a hierarchy of divisions, groups and classes (Figure 3) and assigned a numerical code. For the revised version of CICES abiotic ES have been added to the original set of ES solely focusing on living systems (Haines-Young and Potschin, 2018).

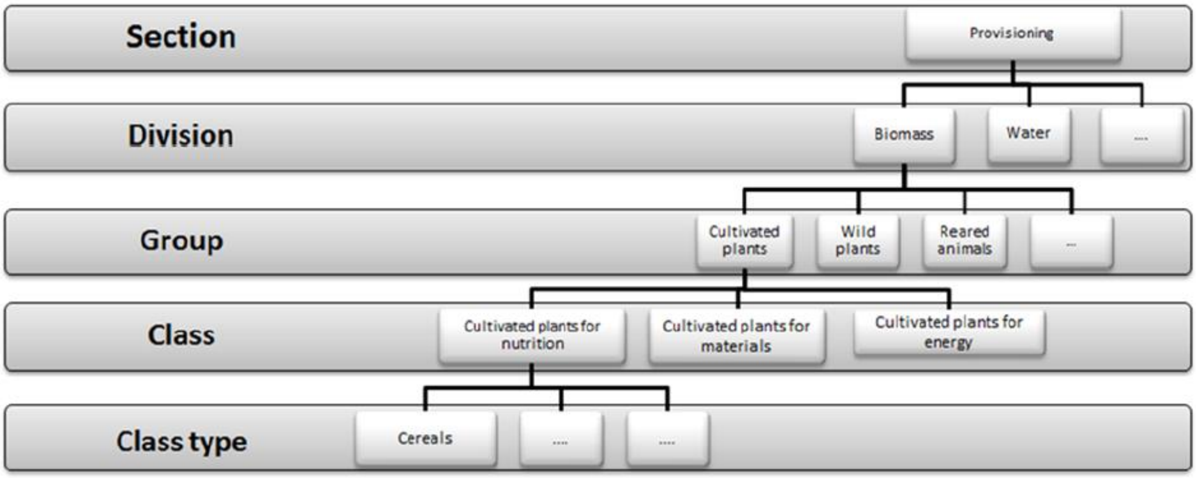


*Figure 4: Hierarchical structure proposed by CICES using provisioning services as an example (Haines-Young and Potschin, 2018).*

## 2 Current challenges

The MEA concluded that humans have changed ecosystems more in the last 50 years than in any comparable period in human history. These changes have resulted from the growing need for food, water, timber, fibre and fuel. The resulting growing economic development has led to an increase in human well-being, but this development was not distributed equally around the globe and has been associated with a significant cost. Many ES have been degraded and inequities among groups of people have been on the rise. Examples of negative ecosystem changes include the conversion of land into cropland, the loss of coral reefs and mangrove area, the increase of impounded water, the doubling of reactive nitrogen in terrestrial ecosystems and the substantial increase of atmospheric concentrations of carbon dioxide. Another finding of the MEA was that humans have significantly changed the diversity of life on Earth leading to a pronounced loss of biodiversity. Especially freshwater species are among the most threatened species. A considerable number of ES are currently being used unsustainably and are degrading as a consequence. For instance, capture fisheries and fresh water are already now exploited beyond sustainable levels. Many of the human caused ecosystem changes have had a profound negative effect on human well-being. There is also evidence that anthropogenic influences increase the likelihood of non-linear changes in ecosystems, which include an accelerating or abrupt rate of change with a potentially irreversible nature. Another finding of the MEA was that drylands are particularly affected by degrading ecosystems. Dryland ecosystems are challenging since they pose a very fragile system in terms of low food productivity high poverty but at the same time are heavily affected by population increase. However, studies show that by applying appropriate and substantial measures in the next 50 years, the degradation of ecosystems can be stopped and even reversed (Millennium Ecosystem Assessment, 2005).

In a recent study, Kaiser et al. (2020) conducted a comprehensive literature research on the effects of river restoration measures on ES. Out of the 850 studies reviewed, only 88 case studies reported quantitative or qualitative effects on ES. According to those 88 case studies, restoration measures led to an increase of 12 ES. Kaiser et al. (2020) highlight the need to adapt existing assessment systems to study the effects of river restoration on ES categories more accurately. Currently, assessment systems vary significantly, which makes a comparative analysis hardly possible. This calls for the elaboration of a more standardized approach for the identification and assessment of ES. The study by Kaiser et al. (2020) found out that mainly regulating and cultural ES benefit from restoration measures. The socio-economic value, however, is not considered in any of the existing legal frameworks, which calls for a revision of these frameworks to specify ES as an important aspect in water management. In general, the effects of river restoration on ES should be studied more precisely and for a longer period to provide a more accurate data basis for stakeholder involved in restoration activities (Kaiser et al., 2020).

# 3 Case studies

This chapter aims to provide examples of national and international case studies, which deal with the effects of river restoration on ES.

## 3.1 Wertach River (Germany)

The Wertach River was subject to various river engineering measures during the 20$^{th}$ century (e.g. river channelization, construction of dams and weirs). These measures led to a decrease of the river width and to an increase of the riverbed slope and consequently, resulting in extensive bed erosion processes, which further affected the ecological situation. Due to these developments, the water management agency started the restoration project “Wertach vital” aiming (i) to mitigate channel incision, (ii) to improve the ecological conditions and (iii) to improve the access to the river for recreational activities (Golfieri et al., 2017).
The restored river stretch is located near the city of Augsburg and is about 14 km long (Figure 5). The projected was carried out between 2000 and 2009 (“Wertach vital I”).


*Figure 5: Location of the restored stretch at the Wertach River near Augsburg (Google maps).*

The restoration measures included the removal of bank protections, flattening of the bed slope and widening of the riverbed. Furthermore, dikes were set back to increase the space for morphodynamic processes and fish ladders were implemented to improve the river continuity (Golfieri et al., 2017). Figure 6 shows the Wertach River before and after the implementation of restoration measures.

*Figure 6: The Wertach River at the Wertachbrücke before (left) and after (right) the implementation of restoration measures (Golfieri et al., 2017).*

For a part of the restored stretch, the EU-funded project HyMoCARES evaluated the effects of these restoration works on ES. The studied river reach is located between the districts of Inningen and Göggingen. The length and area of the study site was 857.5 m and 26.2 ha, respectively. The restoration measures consisted of channel widening and reshaping. Figure 7 visualises the qualitative effects of the implemented channel widening (Boot et al., 2019).

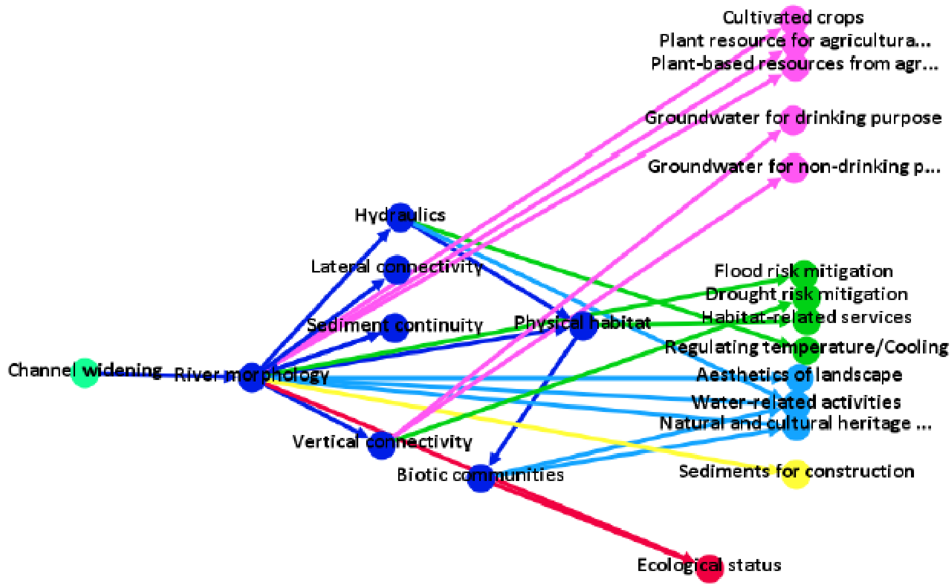


*Figure 7: Hydromorphological processes and ES resulting from channel widening (Boot et al., 2019).*

The HyMoCARES project selected relevant ES and assessed them according to the available data and a set of indicators (Table 2).

*Table 2: ES, indicators and data (Boot et al., 2019).*

| Ecosystem service | Indicator | Data |
|---|---|---|
| **Cultivated crops** | Total production | Corine Land Cover<br>Crop yield (Bayerisches Landesamt für Statistik und Datenverarbeitung) |
| **Habitat-related services** | Hydromorphological status | Regional morphological rating |
| **Aesthetics of landscape** | Diversity of landscapes<br>Rare morphologies | Corine Land Cover<br>Satellite pictures |
| **Natural and cultural heritage** | Ratio of protection areas | Natura 2000 map<br>Landscape protection map |
| **Ecological status** | Ecological status | Regional rating |
| **Flood risk mitigation** | Ratio of safe floodplain | Floodplain map<br>Risk map |

According to the HyMoCARES project, the relevant ES affected by the restoration measures are the following:

- Flood risk mitigation
- Drought risk mitigation
- Regulating temperature/Cooling (water bodies and ground)
- Habitat-related services
- Aesthetics of landscape
- Natural and cultural heritage
- Water-related activities
- Sediments for construction
- Ecological status

The studies regarding the effects of restoration works on ES showed that the channel widening of the Wertach River partially affected ES. While the ES "Aesthetics of landscape" has improved, "Carbon sequestration" has slightly degraded because of deforestation activities. When using the upstream river section as a reference situation, the restoration measure certainly had a positive impact on "Habitat related services". Since the project was conducted several years ago and data prior to the restoration was not available or comparable with the post-data, some ES such as "Ecological status" or "Flood risk mitigation" could not be compared (Boot et al., 2019).

## 3.2 Emscher River (Germany)

The river Emscher located in the federal state of Northrhine-Westphalia in Germany (Figure 8) suffered strongly from past mining activities and industrialization. This caused the river to become poisoned and turning it into an open wastewater channel (Geiß-Netthöfel, 2022).

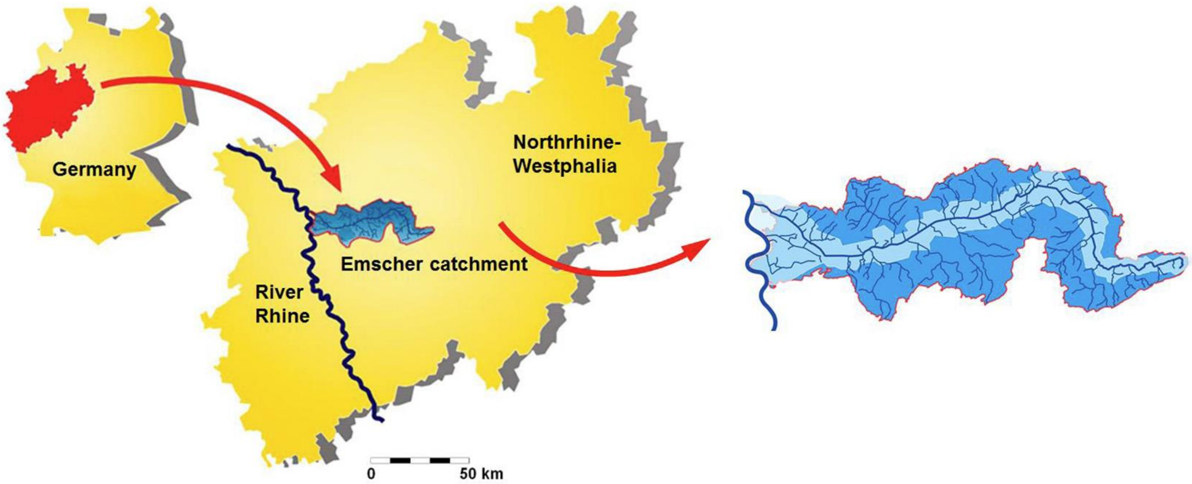


*Figure 8: Case study area of the Emscher catchment (Gerner et al., 2018).*

In order to counteract these effects, the extensive Emscher River restoration project was started in 1990, investing about 5 billion € in the last 30 years of the project. This large-scale project involved the restoration of highly modified open wastewater channels with concrete beds by implementing near-natural river systems. One major aim was to separate the wastewater from the river water and to move the open wastewater channels into the underground. This was achieved in the End of 2021 turning the Emscher into a river free from wastewater (Geiß-Netthöfel, 2022). The removal of the concrete riverbed aims to initiate the widening of the river channel and the creation of secondary floodplains (Gerner et al., 2018). Gerner et al. (2018) conducted a case study, which surveyed the effects of the implemented project in terms of the ES provision and use in the Emscher River and its tributaries. The ES were classified according to the CICES and the Final Ecosystem Goods and Service classification system (FEGS), which divides ES into intermediate ES (e.g. water purification) and final ES (e.g. the use of water for drinking) depending on whether a direct beneficiary (e.g. residential property owners, boaters, researchers) exists or not (Table 3) (Haines-Young and Potschin, 2013; Landers and Nahlik, 2013). For the assessment of the impacts resulting from the restoration measures, Gerner et al. (2018) used an ES evaluation framework by quantifying the regulation and maintenance ES “self-purification capacity”, “maintaining nursery populations and habitats” and “flood protection” as well as cultural ES like aesthetic, recreational, educational and existence values.

*Table 3: Intermediate and final ES of the FEGS classification system with the corresponding CICES classification and beneficiaries (Gerner et al., 2018).*

| Intermediate ESS | CICES section | CICES class | FESS supported |
|---|---|---|---|
| #1: Self-purification:<br>N retention,<br>P retention,<br>C retention | Regulation & Maintenance service | Filtration/sequestration/storage/ accumulation by ecosystems;<br>Dilution by atmosphere, freshwater and marine ecosystems;<br>Hydrological cycle and water flow maintenance;<br>Decomposition and fixing processes | FESS #2, 3, 4 and 5 |
| #2: Maintaining nursery populations and habitats | Regulation & Maintenance service | Maintaining nursery populations and habitats | FESS #2, 3, 4 and 5 |
| **Final ESS** | **CICES section** | **CICES class** | **Beneficiary** |
| #1: Opportunity for placement of infrastructure and reduced risk of flooding | Regulation & Maintenance service | Flood protection | Residential property owners: People living in the floodplain; Industry |
| #2: Opportunity for placement of infrastructure in environment | Cultural service | Experiential use of plants, animals and landscapes in different environmental settings | Resources-dependent businesses (e.g. operators of cafés and restaurants along the restored riverfront) & Residential property owners |
| #3: Opportunity for biking & recreational boating | Cultural service | Physical use of landscapes in different environmental settings | Bikers (leisure time bikers, everyday & workday bikers) & Boaters |
| #4: Opportunities to understand, communicate, and educate | Cultural service | Educational | Educators and students |
| #5: Appreciation that restored stream sections exist | Cultural service | Existence | ‘People who care’ & Residential property owners |

Table 4 shows the various indicators of state, impact I ES provision and impact II ES use for each final ES including the quantified changes in resulting benefit. The monetization of the final ES took place by applying economic methods such as “damage costs avoided”, “contingent valuation”, and “benefit transfer”. Gerber et al. (2018) determined a market value/direct economic impact of 21,441,572 €/y resulting from the restoration measure. This value represents the increased economic activities in this region. A non-market value of 109,121,217 €/y was additionally estimated, which indicates the "non-use value" for the local community taking care of the environment (Gerber et al., 2018).

*Table 4: Indicators of state, ES Provision, ES Use for each final ES and indicators and quantified changes in resulting benefit (Gerner et al., 2018).*

| Final ESS | State indicator | Impact I ESS Provision indicator | Impact II ESS Use indicator | Impact II Resulting benefit indicator | Impact II Resulting benefit | | Unit | Type of economic effect |
|---|---|---|---|---|---|---|---|---|
| | | | | | Before | After | | |
| #1: Opportunity for placement of infrastructure and reduced risk of flooding[1] | Morphometry of stream beds, floodplains and vegetated basins | Potential water retention in total stream length, floodplain and vegetated basin area; Discharge reduction | Avoidance of flooding | Avoided costs of flood damage | 0 | $1.78 * 10^6$ | $€\ y^{-1}$ | Non-market value |
| #2: Opportunity for placement of infrastructure in the environment | State indicators for IESS #1 and #2 | IESS #1 and #2 | A) Commercial places with view on restored river sections | 1) Increased demand for commercial premises at Lake Phoenix | 0 | $8.4 * 10^6$– $19.8 * 10^6$ | $€\ y^{-1}$ | Market value |
| | | | B) Housing area with view on restored river sections | 1) Increased demand for residential property at Lake Phoenix | 0 | $2.5 * 10^6$ | $€\ y^{-1}$ | Market value |
| | | | | 2) Increased demand for residential property in the New Emscher Valley | $11.81 * 10^6$ | $20.44 * 10^6$ | $€\ y^{-1}$ | Market value |
| #3: Opportunity for biking and recreational boating | State indicators for IESS #1 and #2 | IESS #1 and #2 | A) Recreational use by bikers | Expenses for recreational activities by bikers | 0 | $1.33 * 10^6$ | $€\ y^{-1}$ | Market value |
| | | | B) Recreational use by boaters | Expenses for recreational activities by boaters | 0 | 53,600 | $€\ y^{-1}$ | Market value |
| #4: Opportunities to understand, communicate and educate | State indicators for IESS #1 and #2 | IESS #1 and #2 | Acceptance: participation in excursions | Costs for excursions | 0 | 27,840 | $€\ y^{-1}$ | Market value |
| #5: Appreciation that restored stream sections exist | State indicators for IESS #1 and #2 | IESS #1 and #2 | NR | Willingness to pay in appreciation that restored river sections exist | 0 | $107.34 * 10^6$ | $€\ y^{-1}$ | Non-market value |

[1] FESS #1: State: Flooded area at a 100 year flood event *BEFORE*: 126 (ha), *AFTER*: 0 (ha);
Impact I provision: Average discharge in a 100 year event *BEFORE*: 36.41 ($m^3/s$), *AFTER*: 27.66 ($m^3/s$);
Impact II use: Same as impact I provision.

## 3.3 Elbe River (Germany)

The Middle Elbe between the mouth of the river Mulde and Saale is characterised by a huge floodplain of hardwood forests (Figure 9). There, a nature conservation project was conducted by the German WWF and involved the biggest dyke setback in Germany (Naturkapital Deutschland – TEEB DE, 2015).

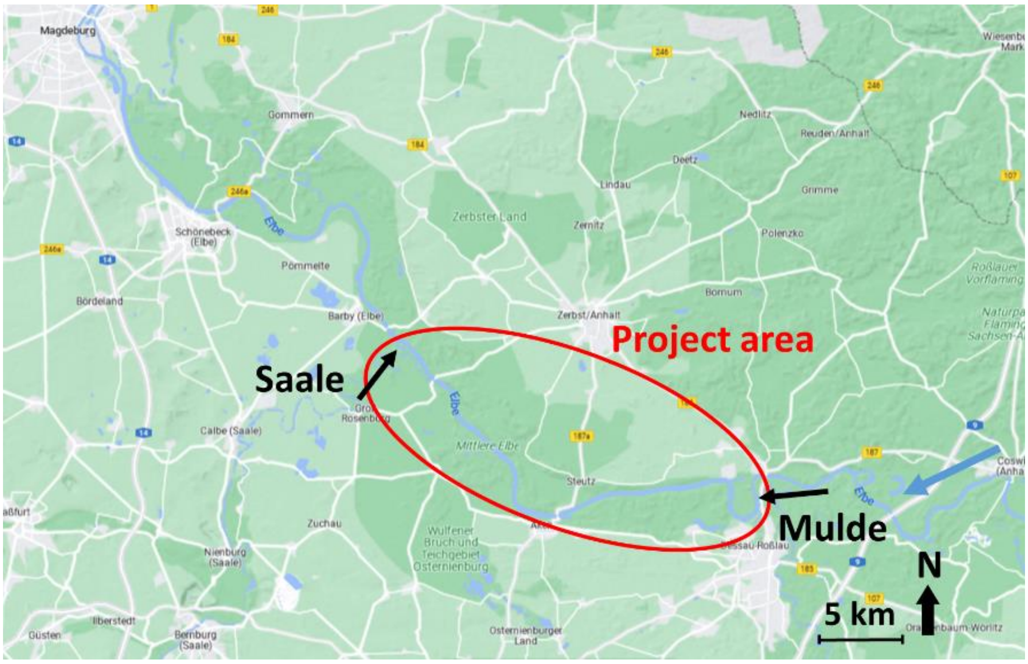


*Figure 9: Poject area at Middle Elbe between the mouth of the rivers Mulde and Saale (Google maps).*

The project was finished in 2018 and aimed to establish and restore near-natural alluvial forests, which can be flooded (Figure 10; Eichhorn et al., 2004). In total, a dyke length of 7.3 km will be constructed. The costs for the dike setback are estimated at ca. 23.2 million € (Naturkapital Deutschland – TEEB DE, 2015).

*Figure 10: The river Elbe and the natural conservation area Lödderitzer Forst during the 2013 flood event (Naturkapital Deutschland – TEEB DE, 2015; Photo: André Künzelmann, UFZ).*

This project comes with a variety of positive effects for ES. By initiating flood dynamics typical for riparian wetlands, near-natural conditions a re-established, which is not only beneficial for the native species and biospheres but also for the promotion of other riparian ES (Scholz et al., 2012). Moreover, numerical models predict improvements for flood protection estimating reduced water levels during floodings of up to 28 cm near the city Aken (LHW Sachsen-Anhalt, 2005). In this area, the floodplain area will be doubled after the finalisation of this project (Naturkapital Deutschland – TEEB DE, 2015). Scholz et al. (2012) further predict that the retention of Nitrogen and Phosphorus will be significantly improved in the riparian wetland near Lödderitz after the setbacks of dykes. Through this increased nutrient retention, the cleaning efficiency of the re-connected wetlands amounts to ca. 700,000 €/y when comparing to the avoided costs resulting from agricultural practices such as reduced use of fertilizers (Naturkapital Deutschland – TEEB DE, 2015). Based on a calculation period of 30 or 90 years, the value for the cleaning efficiency would amount to 13 or 22 million €, respectively. This value is already equal to the costs resulting from the dike setback (Naturkapital Deutschland – TEEB DE, 2015).

At the middle Elbe, 15 dike relocation projects are planned in total, which will lead to the creation of a retention area of 2600 ha. For example, the dike relocation at Rosslau will reconnect a floodplain area of 140 ha (Figure 11). This area fulfils a variety of ES such as flood retention, agriculture, forestry, drinking water supply and recreation area (Scholz, 2016a).

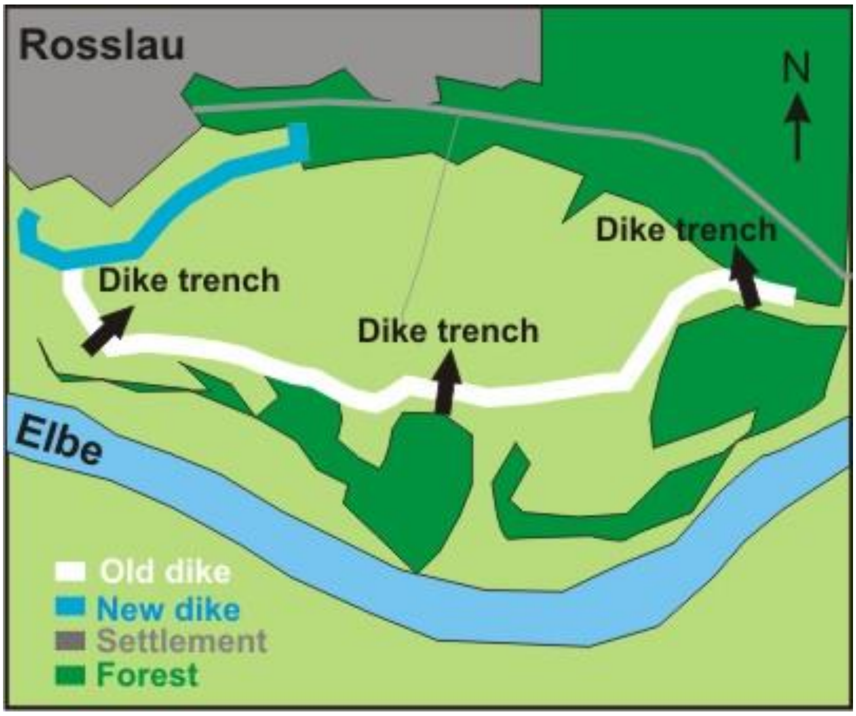


*Figure 11: Dike relocation project at Rosslau (Scholz, 2016a).*

To study the effects of floodplain restoration projects on ES and functions in the Rosslau area, the Helmholtz Centre of Environmental Research (UFZ) established a multidisciplinary research platform in 2006. More than 10 UFZ departments and external organizations are contributing to the project. The project involves a scientific monitoring program and aims to provide solutions for a more advantageous management of dike relocations. The project objectives are (Scholz, 2016b):

- Analyses of biodiversity and ES in floodplains
- Quantification of filtration, transport and buffering processes
- Test of non-invasive monitoring methods for hydrogeology studies
- Prediction of habitat function using biological and environmental factors
- Assessment of potential effects of climate change on floodplain functions and biodiversity
- Integrated approach for mosquito management in floodplains
- Evaluation of the dike relocation from a socio-economical point of view

- Transferability of the results to other floodplain sectors or river systems

## 3.4 Beckingham Marshes at the river Trent (United Kingdom)

The Beckingham Marshes represent a floodplain area of about 900 ha and are located on the left riverbank of the river Trent in Nottinghamshire, in the east Midlands of England (Figure 12). According to Posthumus et al. (2010), the Beckingham Marshes consisted mainly of grassland and marsh, and were used as a retention area to protect the town of Gainsborough until the year 1950. After 1950, the area was converted increasingly into arable land. By the year 2000, nearly the whole floodplain was used for agricultural production of wheat and oilseed rape (Posthumus et al., 2010).

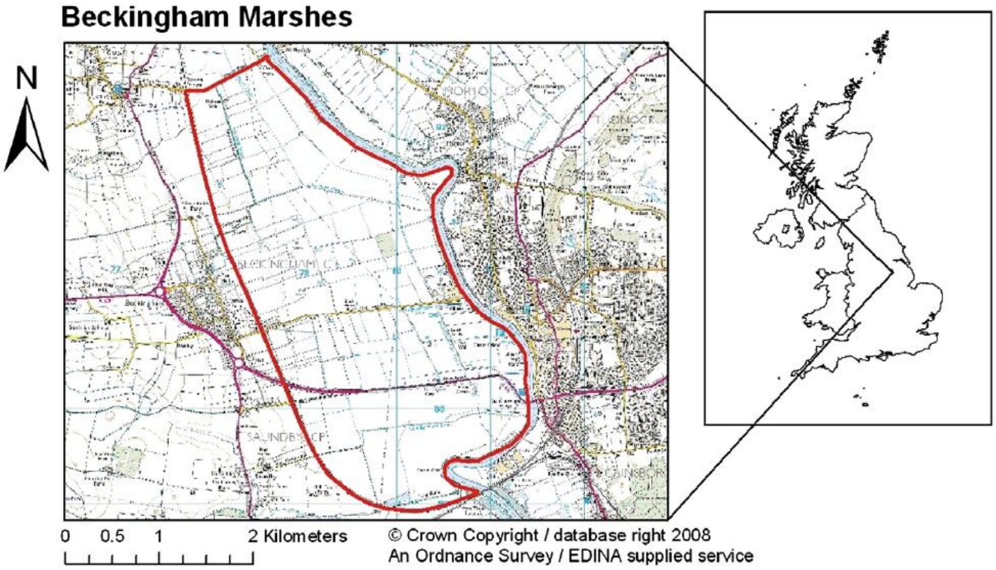


*Figure 12: The Beckingham Marshes at the river Trent in England (Posthumus et al., 2010).*

In 2005, the Environment Agency and the Royal Society for the Protection of Bords (RSPB) jointly implemented the reconversion of 10 % of the floodplain area into wet grassland, in order to establish habitats for wading birds (Posthumus et al., 2010). This measure raised concerns that flood protection and the agricultural productivity could suffer from its implementation leading to potential conflicts between the affected stakeholders and their interests in farming, flood protection management and habitat provision. Due to these potential conflicts, six alternative land use scenarios were elaborated to analyse the advantages and disadvantages to derive ecosystem services from the different land uses (Posthumus et al., 2010):

1) Current situation: This scenario involves the preservation of the situation in 2006 consisting of the agricultural production of winter wheat, oilseed rape, field beans and peas.
2) Agricultural production: This land use type is similar to the 2006 situation but agricultural production is more intensified.

3) Agri-environment: This scenario aims to improve biodiversity but to use the land mainly for agricultural purposes. This could be done by a combination of wet grassland and hay meadow, which are not sensitive to medium-duration flood events.
4) Biodiversity: This scenario is comparable to the "Agri-environment" scenario but with no constraints in terms of agricultural production. It would turn the Beckingham Marshes into an area of reed bed, wet woodland and wet grassland.
5) Floodwater storage: The objective of this scenario is to increase the retention of floodwater as much as possible by using the Beckingham Marshes as an agricultural area for the production of cereals.
6) Income: This scenario aims to maximise the income out of the land use. For this scenario, one of the above mentioned land use types are chosen that shows the highest estimated annual profitability per hectare.

The study by Posthumus et al. (2010) determined normalised values of various indicators for the different land use scenarios (Figure 13). The agri-environment and income scenarios achieve the highest values for ecosystem goods and services. The study by Posthumus et al. (2010) sowed that there exist both synergies and conflicts between the studied ES obtained from lowland floodplains like the Beckingham Marshes. For example, there are synergies between agricultural production and short-duration floodwater storage. Potential conflicts exist for example, between floodwater storage and biodiversity since some wetland habitats and species are sensitive to flood events (Posthumus et al., 2010). This case study further showed that modelling scenarios for different types of land uses can help decision makers to find the optimum solution to satisfy the different interests of stakeholders.

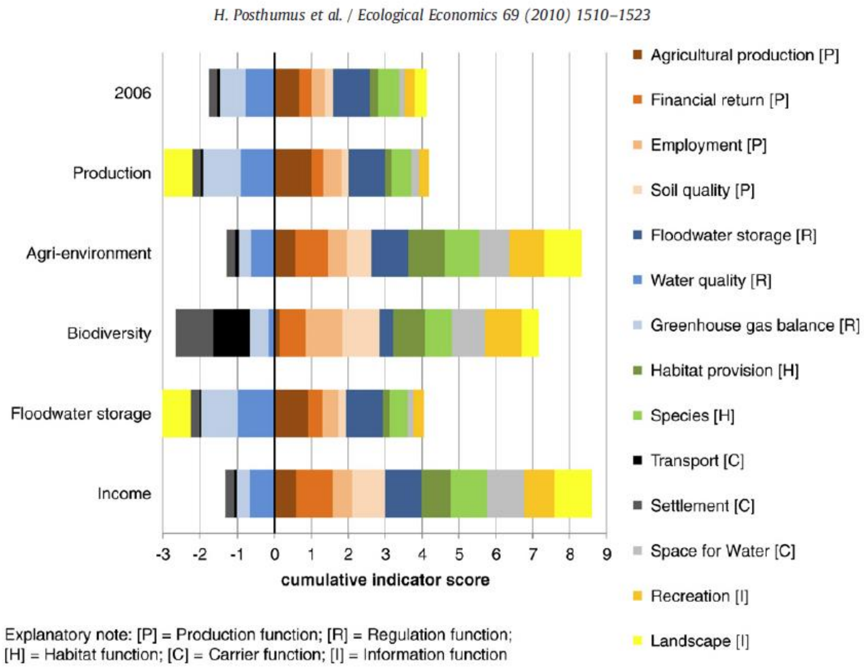


*Figure 13: Normalised scores for ecosystem goods and services of the different land use scenarios (Posthumus et al., 2010).*

### 3.5 Danube Floodplain National Park (Austria)

The Danube Floodplain National Park is the largest natural floodplain in central Europe showing a size of 96 km². Figure 14 gives an overview of the National Park, which is located east of the city of Vienna in Austria and consists of seven side-arm-systems. In the past, this river section has undergone major morphologic and hydrodynamic changes. At beginning of the 19th century, river engineering works (e.g. channelization, regulation, disconnection of the floodplain from the main channel) were performed for reasons of navigation and flood protection. The construction of hydropower plants started in the 1950s and additionally led to changes in the natural dynamics of the river system (Habersack et al., 2016).

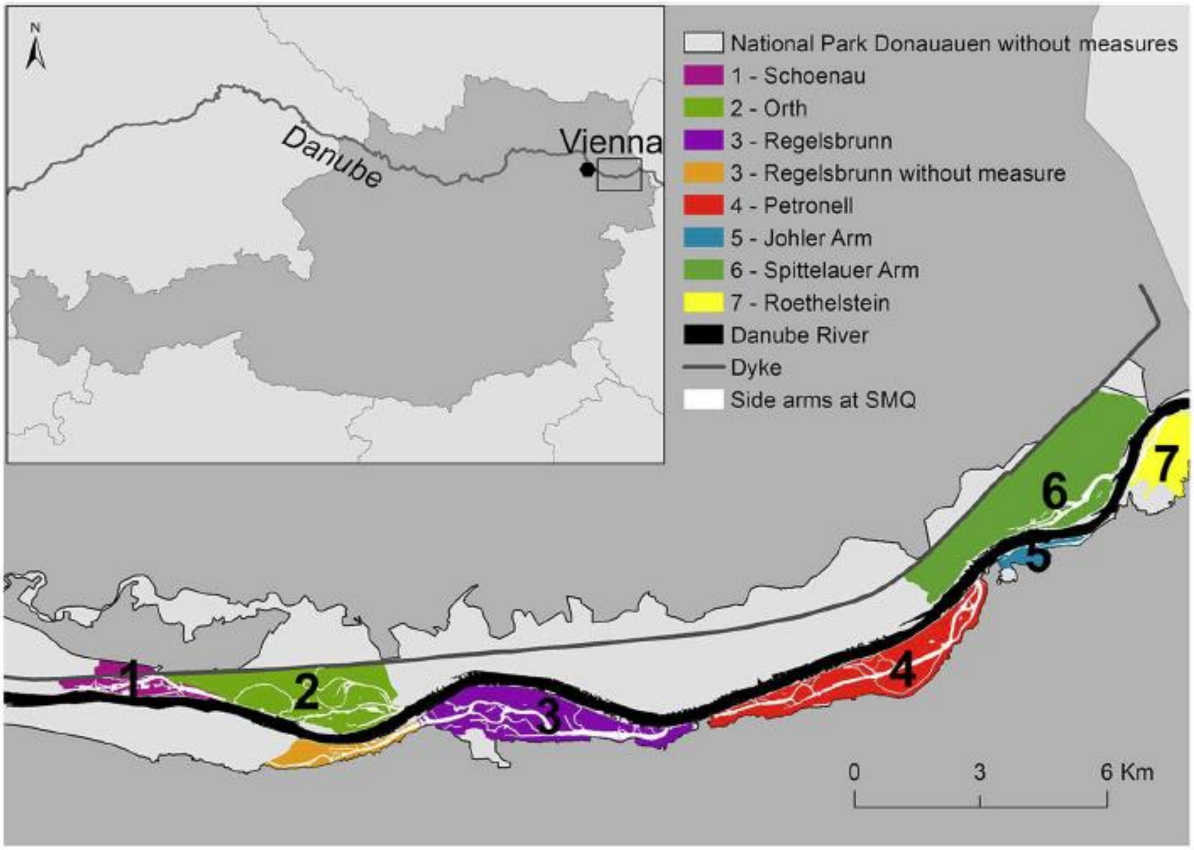


*Figure 14: The Danube Floodplain National Park east of Austria's capital Vienna (Natho et al., 2020).*

In order to improve the ecological situation, the reconnection of side arms started in 1996 (Natho et al., 2020). The effects of the reconnection of the Danube floodplain were assessed through the European project "Aquamoney". In this project, researchers from more than 10 European Countries collaborated to evaluate the ecosystem services resulting from these restoration measures (Brouwer et al., 2009).

Amongst other ecosystem services, the side arm systems in the Danube Floodplain National Park act as retention basins for nitrate and phosphorus. Four side arms were partially reconnected to a different extent in the national park Donauauen by 2020. To assess the effect of these river restoration measures on the retention of nutrients, Natho et al. (2020) modelled two scenarios: (i) current state and (ii) all seven side arms are reconnected and consistent water levels are maintained by sediment nourishments. Both scenarios were modelled for different hydrological conditions (for the extremely wet year (2002) and dry year (2003)) and considering also the effect of the planned reconnection of several side arms. Natho et al. (2020) used both a statistical model and a semi-empirical retention model and compared the results. Monitoring data of the hydrology, nitrate and total phosphorus concentrations was available for three side arms (Natho et al., 2020).

The study by Natho et al. (2020) showed that the nutrient retention by the floodplain mainly depends on the hydrological connectivity. Figure 15 illustrates the contribution of the side arm systems to the nutrient retention in the wet year 2002. The large side-arm systems with low connectivity under current conditions had the biggest reconnection effect in terms of nutrient retention. The application of both the statistical and the semi-empirical model provided results in a comparable range of the retention of nitrate (77 - 198 kg/ha y) and total phosphorus (1.4 - 5.7 kg/ha y).

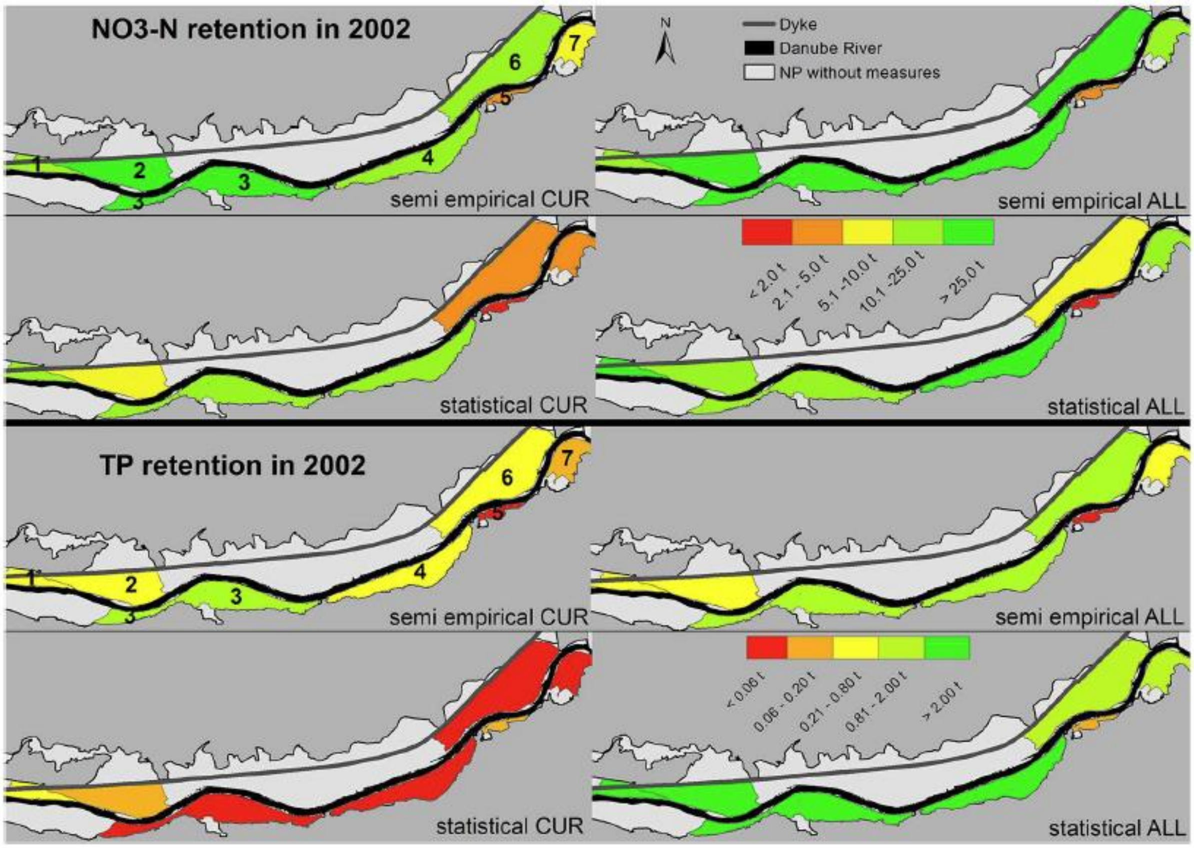


*Figure 15: Retention of nitrate ($NO_3$-N) and phosphorus (TP) by the different side arm systems in the wet year 2002 (Natho et al., 2020).*

This study further found out that the retention of 1 % of the total load of dissolved inorganic nitrogen (119,015 t in the dry year 2003 and 199,000 t in the wet year 2002) and of total phosphorus (2,699 t in the dry year 2003 and 6,700 t in the wet year 2002) requires the reconnection of 10 – 15.5 times more floodplain area. Frequent inundations of floodplains are not only a basic requirement to retain nutrients by denitrification and sedimentation but they are also beneficial for many other ES provided by floodplains such as habitat provisioning. Compared to occasional floodings of floodplains, Natho et al. (2020) argue that the complete reconnection of side arms result in a higher nutrient retention. However, the studied floodplain area by Natho et al. (2020) is too small to achieve a significant reduction of the nitrate and phosphorus loads in the Upper Danube. The reconnection of side arm systems contributes considerably to better water quality in the main channel of the Danube River, which therefore shows the benefits of activating more floodplains.

### 3.6 Ebro River (Spain)

The Ebro River is located in the northeast of Spain. The river has a length of 930 km and a catchment size of 85,000 km² (Ollero, 2010; Figure 16).

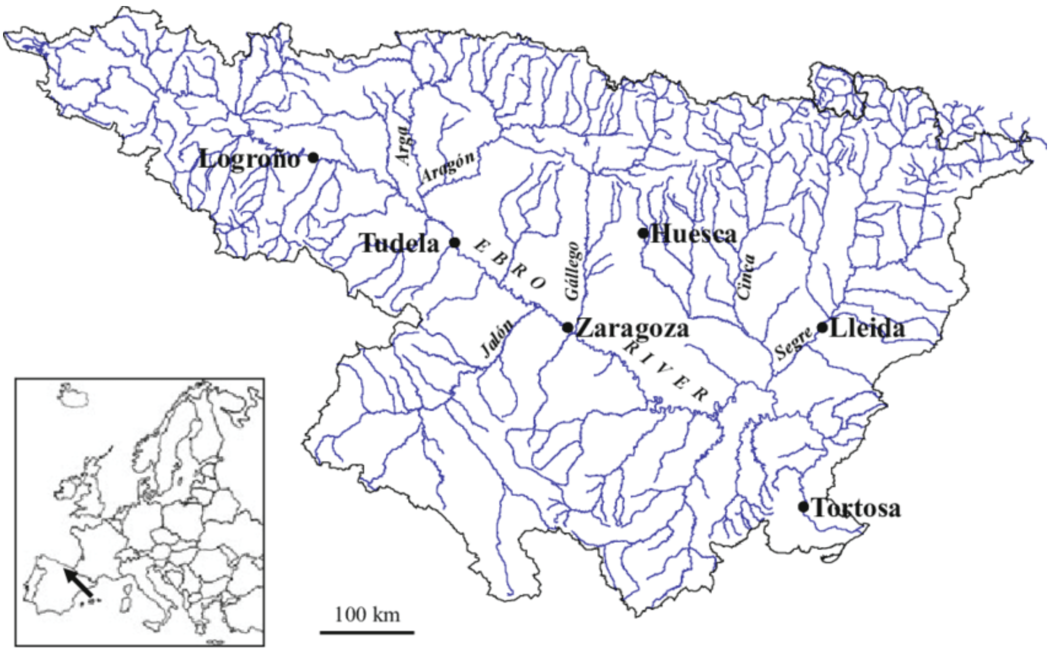


*Figure 16: The Ebro River catchment in the northeast of Spain (Romani et al., 2010).*

The middle section of the river Ebro was subject to major morphologic alterations in the past. The construction of large reservoirs and embankments aimed to protect agricultural land from flood events. However, these measures were not as successful as expected leading to even more destructive floodings than before the construction. Besides, sediment retention in the reservoirs resulted in a lack of sediments downstream of the dam and consequently, the erosion of the riverbed. Due to the riverbed level decrease, side channels were disconnected from the main channel and groundwater lowering occurred. In order to counteract these developments in at least some floodplains, restoration measures started in 2006 in Soto

Tetones, along a floodplain of 113 ha. This floodplain is situated 3 km upstream of the town of Tudela. In 1970, the Seto Tetones floodplain was used for intensive rice cultivation, which resulted in the disappearance of riparian wetlands and increased flood risk problems. Figure 17 shows the agricultural land before, during and after the rice crop (Gumiero et al., 2013).

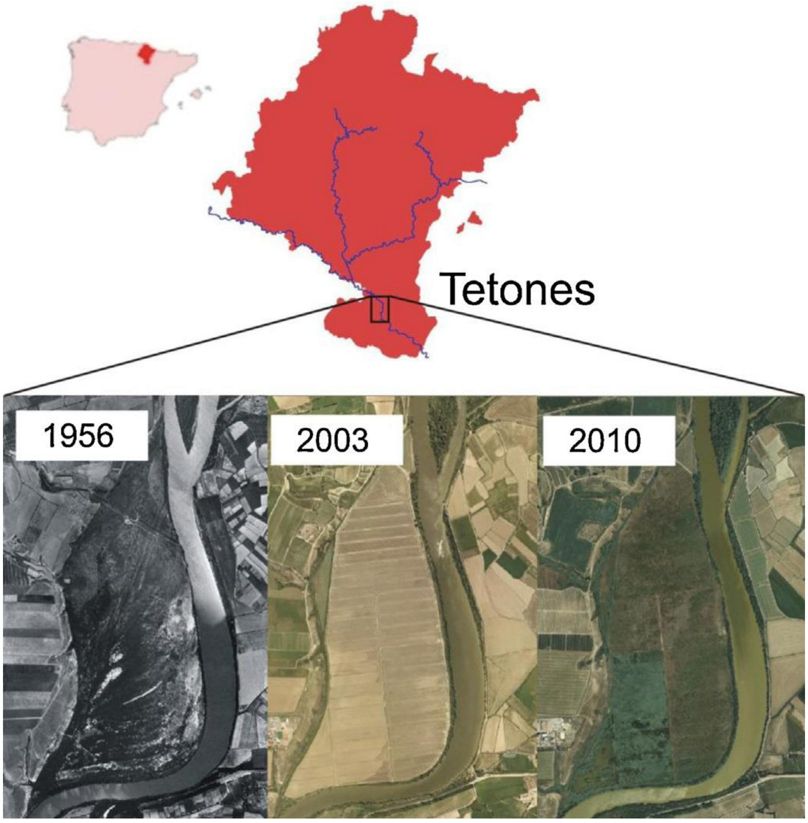


*Figure 17: Soto Tetones before (1956), during (2003) and after (2010) rice crop (Gumiero et al., 2013).*

With time, the agricultural use in combination with insufficient watering of the floodplain resulted in impermeable soil layers due to fine sediment accumulation on the rice fields. Consequently, groundwater recharge was impeded and salinity concentrations in the soil increased because of the changed hydrological conditions. In addition, the construction of roads and concrete channels for irrigation purposes had further negative impacts on hydrologic dynamics and rice cultivation. To overcome these adverse developments, restoration measures included the removal of embankments and deep-ploughing of the consolidated agricultural land, in order to allow more frequent floodings and to increase soil permeability and groundwater recharge. The objectives of these measures were to restore more dynamic flow regimes and to improve the ecological situation in the floodplain area. These measures were very effective as the floodplain was flooded more often and vegetation typical for riparian zones began to grow. Mediterranean river forests such as White Poplar, French Tamarisk, Black Poplar and Common Ash started to colonize in the southern part of the floodplain. Because of the restored groundwater connectivity, aquatic vegetation (e.g. Broadleaf Cattail, Prairie Rush, Common Reed) started to emerge. To sum it up, the restoration measures resulted in the development of heterogenic habitats for aquatic birds, as well as for pond turtles and European protected species like Otter and European mink. This floodplain restoration showed that natural flow dynamics including regular floodings are important to establish an ecological functioning riparian wetland. By transporting sediments into the floodplain and thus, providing material for the emergence of gravel bars and islands, valuable habitats for riverine species can be initiated (Gumiero et al., 2013).

### 3.7 Cornwall and Devon Basin (United Kingdom)

The Westcountry Rivers Trust (WRT) is a charity organisation, established in 1994 with the general objective to preserve and restore the freshwater environments in the southwest of England. Figure 18 gives an overview of five WRT's river restoration projects in Cornwall and Devon, which were funded by the River Restoration Fund. NEF (New Economics Foundation) consulting analysed these projects in respect of the effects on ES and environmental and socio-economic aspects in general, which are:

1. The Par, St Austell and Caerhays basins, St Austell bay area (SCRIP)
2. The Exe and Axe catchments (AERIP)
3. The Dart and the Teign basins (DTRIP)
4. The Avon catchment, encompassing as well as the Erme and the Yealm rivers (SHRIMP)
5. The Taw basin (TRIP)

The objectives of the respective projects were to improve (i) water quality (reducing diffuse pollution), (ii) biological diversity and (iii) wider riparian ecosystem conditions in the respective catchment areas (Vardakoulias and Arnold, 2015).

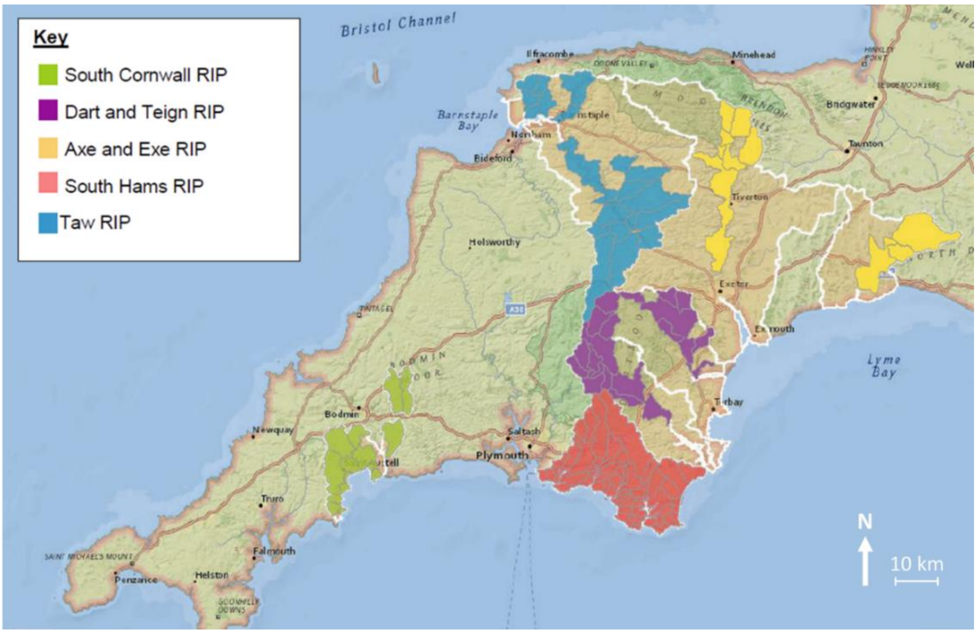


*Figure 18: Map of River Improvement Projects (RIPs) with respective catchment areas (white outlines). The coloured areas mark the individual project areas (Vardakoulias and Arnold, 2015).*

The restoration measures in the RIPs included the improvement of (i) the longitudinal connectivity of rivers, (ii) the in-channel structures and the substrate and (iii) the riparian zone. The longitudinal connectivity could be improved either by removing existing culverts and weirs or by implementing fish passes. The improvement of in-channel structures and substrate could be established by gravel augmentations favourable for salmonid spawning. Another measure was to insert substrates such as large woody debris or boulders, which can provide valuable habitats for fish and other aquatic species. Measures to improve the riparian zone involved the development of farming management plans to reduce pollution caused by fertilizers and pesticides. Further measures were the installation of fences to prevent faecal contamination by livestock and to implement coppicing, which is beneficial for tree health and riverbank stabilization (Vardakoulias and Arnold, 2015).

In the assessment of the projects, an extended Cost-Benefit Analysis was applied to determine the socio-economic and environmental benefits provided by the restoration measures. The following aspects were studied:

- The potential environmental (ecological) impacts of the respective projects
- The potential societal benefits supported by those ecological impacts
- The value of those benefits, expressed in monetary terms
- The Benefit-Cost ratios, i.e. the comparison between the investments put in the projects and the wider benefits generated.

The general outcome of the studies is that all restoration projects resulted in comprehensive benefits for society and various ES. Table 4 presents the results of the Cost-Benefit Analysis indicating that the cost-benefit ratio lies between £ 1.9 and £ 4.5 depending on the project area. Since the Net Present Value, which describes the economic efficiency of an investment, shows positive values for all projects, the conducted investments in river restoration were economically efficient (Vardakoulias and Arnold, 2015).

*Table 5: Results of the Cost-Benefit Analysis under assumption of a 10 year benefit period and a 3.5 % discount rate (Vardakoulias and Arnold, 2015).*

| | Net Present Value | Benefit:Cost Ratio |
|---|---|---|
| **Dart & Teign RIP** | £1,088,572 | 4.53 |
| **Axe & Exe RIP** | £979,908 | 3.93 |
| **South Hams RIP** | £948,471 | 3.37 |
| **South Cornwall RIP** | £211,324 | 1.91 |
| **Taw RIP** | £2,652,016 | 3.39 |
| **TOTAL** | £5,880,291 | 3.46 |

The resulting benefits obtained from the restoration projects are predominantly increased commercial fish catch and increased tourism (Figure 19). Benefits from clean freshwater and from increased farm revenue are also considerable. Minor benefits are obtained for recreational anglers and other recreational users (Vardakoulias and Arnold, 2015).

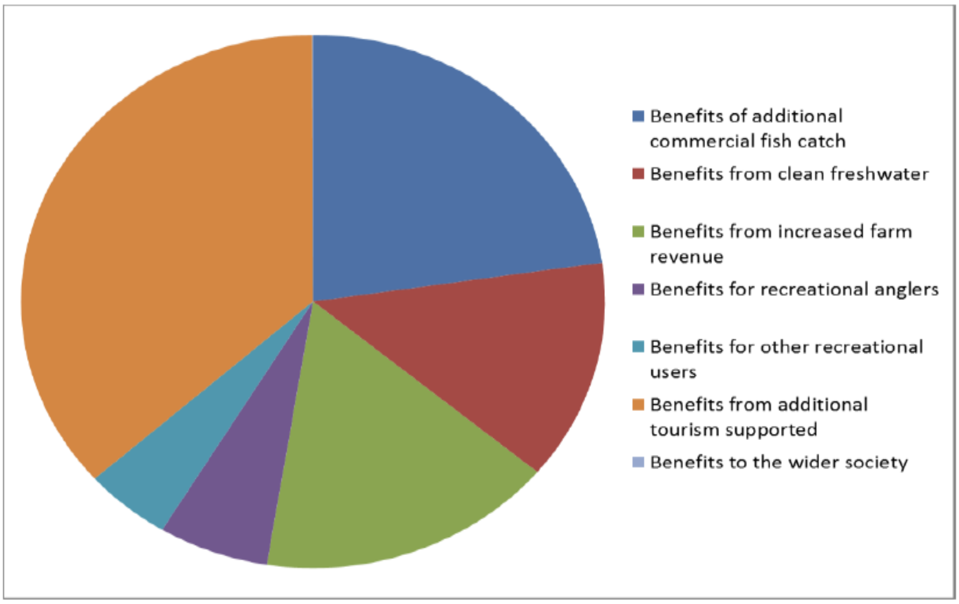


*Figure 19: Different type of benefits provided by the RIPs (Vardakoulias and Arnold, 2015).*

### 3.8 Various case studies across Europe

Vermaat et al. (2016) estimated the effects of restoration measures at eight study sites across Europe. Figure 20 shows the locations of the respective case studies, which each consisted of restored and unrestored river stretches and floodplains. For the individual habitats within each stretch, Vermaat et al. (2016) assessed the provisioning (agricultural products, wood, reed for thatching, infiltrated drinking water), regulating (flooding and drainage, nutrient retention, carbon sequestration) and cultural (recreational hunting and fishing, kayaking, biodiversity conservation, appreciation of scenic landscapes) services. The resulting monetary benefit was estimated based on available data, literature, surveys conducted among inhabitants and visitors, and by applying various economic methodological approaches such as market value, shadow price, replacement cost, avoided damage, willingness-to-pay survey and choice experiment (Vermaat et al., 2016).


*Figure 20: Overview of analysed river restoration measures by Vermaat et al. (2016).*

Table 6 gives a detailed overview of the analysed case studies by Vermaat et al. (2016). The restoration activities included for example, measures to re-meander, re-landscape and lower the floodplains. Further measures involved the reconnection of side arms, riverbed widening, installation of fish passes and gravel augmentations for the provision of spawning habitats for salmonids (Vermaat et al., 2016).

*Table 6: Detailed characteristics of the analysed case studies (Vermaat et al., 2016).*

| River | Regge (The Netherlands) | Skjernå (Denmark) | Mörrumsån (Sweden) | Vääräjoki (Finland) | Narew (Poland) | Becva (Czech Republic) | Enns (Austria) | Drau (Austria) |
|---|---|---|---|---|---|---|---|---|
| Coordinates (°.'N, E) | 52.30, 6.23 | 55.54, 8.23 | 56.18, 14.43 | 63.11, 24.02 | 53.08, 22.52 | 49.27, 17.28 | 47.25, 13.49 | 46.45, 13.19 |
| Mean annual discharge ($m^3 s^{-1}$) | 11 | 35 | 25 | 10 | 17 | 18 | 22 | 63 |
| Floodplain slope ($m\ km^{-1}$, linear, upstream of reach, $r^2$ indicates goodness of linear fit) | −0.207 ($r^2 = 0.15$) | −0.604 ($r^2 = 0.78$) | −0.872 ($r^2 = 0.65$) | −0.376 ($r^2 = 0.20$) | −0.255 ($r^2 = 0.56$) | −1.565 ($r^2 = 0.58$) | −2.882 ($r^2 = 0.48$) | −5.392 ($r^2 = 0.79$) |
| surrounding landscape | Mainly flat, sandy dairyland with glacial moraine ridges | Extensive sandy flat plateaus dissected by broad periglacial tunnel valleys, mainly under agriculture | Forested bedrock hills with interspersed bogs and river valley under agriculture | Forested bedrock hills with interspersed bogs and river valley under agriculture | Gently rolling plateaus under agriculture of variable underlying geology interspersed by marshy, wide periglacial river valleys | Floodplains and foothills largely agricultural, upslope Carpathian mountains under forest | Comparatively broad alpine valley with agriculture at the bottom and forest and rangelands higher up | Comparatively broad valley with agriculture at the bottom and forest and rangelands higher up |
| Restoration measures | Re-meandered, re-landscaped and lowered the floodplain | Re-meandered, re-connected old arms, reduced depth in main channel, re-landscaped and lowered the floodplain | Enhanced minimal flow with hydraulic measures, added gravel beds, facilitated upstream fish migration | Returned large boulders into the river bed, reconstructed gravel beds for spawning salmonids | Floodplain re-wetting with a downstream weir, reconnect side arms, | Allow natural channel development and migration after unprecedented flood event in summer 1997 | Stream bed widened and side arm re-opened, | Stream bed widened and side arm re-opened, |
| Length restored–unrestored (km along main stream axis) | 1.1–0.7 | 2.6 (in a much larger project)–1.5 | 3.1–2.4 | 16–30 | 4–5 | 7 (part of a much larger project)–7 | 0.7–0.8 | 2–1 |
| Number of interviewed people, % visitors, % willing to respond | 100, 30%, not recorded | None (benefit transfer) | 47, 23%, 20% | 67, 14%, not recorded | 100, 14%, 30% | 27, 44%, 30% | 71, 10%, 50% | 112, 20%, 51% |
| Estimated resident population represented by the interviewed sample | 8400[a] | – | 31,000 | 6010 | 130,000 | 74,000 | 3351 | 5446 |
| Choice experiment design, attributes and associated range of additional annual water tax payment per household[b] | Accessibility (3 levels), flood risk (1 in 10, 25, 100 y), water quality (3); 0–25€ | – | Accessibility (3), hydropower (3), presence migrant salmonids (3), 0–20€ | Landscape aesthetics (3), length restored (3), ecological status (3), 0–70€ | Landscape quality (3), biodiversity (3), water quality (3), 0–60 PLN | Landscape aesthetics (3), flood risk (3), biodiversity (3), 0–150 CZK | Accessibility (3), flood risk (3), ecological quality (3), length restored (3), 0–30€ | As Enns |
| Period interviews | April 2013 | – | May 2014 | May 2013 | August 2013 | September 2014 | April–May 2014 | May–June 2014 |
| Main source | Brockhoff (2013) | Dubgaard et al. (2005), Pedersen et al. (2007) | Coersen (2015) | Plug (2014) | Gradzinski et al. (2003), Gielczewski (2003), Banaszuk et al. (2005), Banaszuk & Kamocki, (2008), Tylec (2013) | Kohut (2014) | Haverkamp (2014) | Haverkamp (2014) |

Underlined references are our own local case studies a.o. containing the wtp-surveys. The Regge is locally known as Beneden Regge

[a] Estimated from the percentage willing to be interviewed, the percentage residents in the sample and the most recent reported population of the riparian municipality. Brockhoff (2013) estimated the existence value of the biodiversity component of cultural service from the wtp and the total visits of 8400 during the tourist season of 7 months; he did not estimate the percentage of non-respondents, and adjacent villages have a population of 14,000, which is not so high that we considered it necessary to include an extra value due to non-visiting residents

[b] Each choice experiment compared two alternatives with the status quo in 6 or 8 choice cards. Card combination allocation was either optimized or fully random (Vääräjoki, Narew). Water quality and ecological status were chosen to correspond with status levels of the European Water Framework Directive

Vermaat et al. (2016) studied the relation between ES derived from restoration measures with floodplain and catchment characteristics. The results showed a correlation between cultural and regulating services with the density of human population, livestock and agricultural nitrogen surplus in the catchment but not with amount agricultural land or forest, floodplain slope, mean discharge or gross domestic product (GDP). In the restored river stretches and floodplains, the total ecosystem service was increased by 1,400 €/ha y. According to Vermaat et al. (2016), the reduction of flood risk and the appreciation of the natural landscape depend on population density but is independent from richness in those parts of the case studies where dairy farming is the predominant agricultural practice. Vermaat et al. (2016) argue that cultural services profited predominantly from the restoration measures. Regulating services were less increased, whereas provisioning services were not affected at all by the restoration activities. However, impacts among the different case studies varied considerably with slightly adverse effects resulting from the restoration measures at one case study (Finnish Vääräjoki) or with provision services being repealed by the high flood risk in the unrestored stretch (e.g. at the Czech Becva).

# 4 Conclusion

To conclude, the present review study showed that numerous national and international examples exist, which deal with the effects of river restoration measures on ES. Some of them were described in chapter 3, in order to get more insights on the ecological benefits deriving from such restoration activities. For a proper assessment of ecosystem services, three major classification system were developed in the past. These are (i) the Millennium Ecosystem Assessment (MEA), (ii) the Economics of Ecosystems and Biodiversity (TEEB) and (iii) the Common International Classification of Ecosystem Services (CICES). The literature review further showed that the increase of the human population in combination with the growing need for resources have resulted in an enormous degradation of ES worldwide. Negative effects on ES include for instance, soil sealing due to land use changes, ecological degradation of river sections caused by the construction of impoundments, and the increase of carbon dioxide concentrations in the atmosphere due to the rise of anthropogenic $CO_2$ emissions. Based on the present literature review however, the awareness to invest more efforts in the improvement of riverine ecology is clearly growing. The increasing number of case studies over the past years is proof for the fact that the ecological degradation can be stopped and even reversed. Nevertheless, there is still a need to raise the number of restoration measures to compensate adverse developments from the past and to achieve further improvements for riverine ecology.

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# 6 Lists

## 6.1 List of figures

## 6.2 List of tables