Benefits of European river restoration schemes

An analysis of 13 case studies aiming to integrate improvement of ecological conditions and flood risk mitigation

Wetlands INTERNATIONAL

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Cover photo: restored reach of the Drac

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Introduction

River restoration refers to ecological, physical, spatial, and management measures and practices aimed at restoring a more natural state and functioning of the river system in support of biodiversity and of several key ecosystem services, such as flood and drought risk mitigation, aquifer recharge, nutrient retention, recreation. River restoration is an integral part of sustainable water management and directly supports the aims of the Water Framework Directive, as well as of national and regional water management policies.

Two main drivers often trigger river restoration measures, namely improving the ecological status of water bodies and biodiversity, and reducing flood risk. However, evidence of the effects of River Restoration measures in relation to both these objectives ("integrated restoration measures") is still limited. The goals of this review have been to confirm whether tangible examples of "integrated restoration" are available for all the main categories of such measures (see par. 2 for definitions) and to verify to what extent evidence of effects and benefits is available. Rather than being exhaustive, this review aims at fostering the discussion on measures for integrated restoration.

The analysis has been carried out through a review of existing databases, including the LIFE+ RESTORE wiki, the FP7 REFORM wiki, and some national databases. This report aims to underpin the replication of successful river restoration initiatives across the regions and to give suggestions on how to improve the way that European water policy can be implemented.

1. Findings

The first result of this review has been that for most of the categories of "integrated restoration measures", as defined in par.2, several examples of projects implemented in the EU are available. Most of these projects mention the reduction of flood risk as a primary, or at least, secondary goal and are described as successful. Additional **benefits** which are found through monitoring and evaluation of the projects include:

- Increase in biodiversity (improved spatial distribution and/or abundance of species) and flagship species making a comeback as a result of habitat restoration;
- Improved conditions and/or rejuvenation of riparian vegetation; improvement of ecological and morphological status.
- Contribution to sustainable regional development and tourism.

Several of the projects analysed implemented active **public participation** and awareness raising activities and the involvement of stakeholders facilitated a successful implementation.

Nevertheless, an **exhaustive quantification of the benefits of these projects is seldom available**, especially in relation to flood risk reduction. This is not surprising as it has been highlighted by several previous literature reviews (see e.g. Bash et al., 2002; Bernhardt et al., 2005; Palmer et al., 2010; Roni et al., 2013; Morandi et al., 2014; Kail et al., 2015; Rubin et al., 2017). In general terms, despite the relatively high number of restoration schemes implemented in the last decades, consistent evidence of the effects of restoration is still too limited. Part of this is due to the fact that **project monitoring and assessment are still carried out in a minority of cases**. But even where the monitoring effort has increased significantly, the results often remain to a significant extent ambiguous, due to **critical gaps in the approaches** implemented, including insufficient spatial and temporal scales of monitoring, lack of reference conditions, insufficient consideration of all the cause-effects relationships involved, and permanence of other kind of interfering pressures in the upstream catchment.

Besides this general issue, this review also highlighted the **need to update and improve the existing sources of information on river restoration**. Despite the existence of extensive lists of projects in dedicated databases implemented by EU funded projects, sometimes these show an insufficient homogeneity in the definition of the measures and a lack of relevant details or of updated information in the project description. National databases and project reviews, promoted by public administrations in charge of river basin management, are still scarce. Among these, the most relevant is probably the review of morphological restoration projects published by Onema (*Office national de l'eau et des milieux aquatiques*), now *Agence Francaise pour la Biodiversité*[1]. Another example is the recently published evidence base for working with natural processes to reduce flood risk, by the UK Environment Agency.[2]

[1] It can be found at http://www.onema.fr/node/2519

[2] Online available at: http://ow.ly/NJjc30havvr

European policy context

The water policy within the European Union has increasingly protected water in the last thirty years. Considerable success has been achieved in reducing the pollution from urban, industrial and agricultural sources to tap water as well as coastal areas, rivers and lakes. Quality of European waters has improved, particularly by treating urban wastewater and thus reducing the concentration of oxygen-consuming substances and ammonium in water bodies[3]. This, combined to improvements of longitudinal continuity, created the opportunity for the return of iconic fish species, such as salmon and sturgeon, in some places along European rivers[4]. However, much work still remains to be done in terms of restoration, and of policy effectiveness. For instance, the targets set by the EU itself in the Water Framework Directive (see below) for 2015, have been disregarded in almost half of the water bodies that are still in less than "good status".

Water Framework Directive

The EU Water Framework Directive (WFD, 2000/60/EC) aims at enhancing the status of aquatic ecosystems and biotic communities in a comprehensive way. Water management is brought beyond water quantity and quality, entailing prescriptions on land-use as well as on the governance. The WFD sets objectives in terms of good status, with a deadline by 2015.

Flood Risk Management Directive

The EU Floods Directive (2007/60/EC) aims to reduce flood risk of vulnerable territories and populations. Article 7 specifies that Flood risk management plans may also include the promotion of sustainable land use practices, improvement of water retention as well as the controlled flooding of certain areas in the case of a flood events.

Commission Communication on Green Infrastructure

Green Infrastructure (GI) refers to a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. Their development boosts disaster resilience among other goals, making them an integral part of EU policy on disaster risk management. In practice, functional floodplains, riparian woodland, protection forests in mountainous areas, barrier beaches and coastal wetlands are combined with "grey" infrastructures, such as river protection works, to reduce impacts on human society and the environment. The Commission fosters GI by creating an enabling framework to encourage and facilitate projects within existing legal, policy and financial instruments to exploit their benefits for sustainable development.[5]

Blueprint to Safeguard Europe's Water Resources

The Commission published the Blueprint with the aim to ensure that a sufficient quantity of good quality water is available for people's and environment's needs and activities throughout the EU. The Blueprint promotes alternative land use practices for contributing to the achievement of WFD good ecological status. Among them,

[3] From: "EEA Report 9/2012. European waters – current status and future challenges (Synthesis)"

[4] From "COMMUNICATION FROM THE COMMISSION. A Blueprint to Safeguard Europe's Water Resources." COM/2012/0673

[5] From "COMMUNICATION FROM THE COMMISSION. Green Infrastructure (GI) — Enhancing Europe's Natural Capital." COM/2013/0249

Natural Water Retention Measures (NWRM) are integrated in the WFD Common Implementation Strategy[6].

NWRM guidance

> *Natural Water Retention Measures are multi-functional measures that aim to protect water resources and address water-related challenges by restoring or maintaining ecosystems as well as natural features and characteristics of water bodies using natural means and processes. The main focus of applying NWRM is to enhance the retention capacity of aquifers, soil, and aquatic and water dependent ecosystems with a view to improve their status[7].*

NWRM are promoted as suitable tools to implement water management, and river restoration within the EU policy framework and objectives. Their rate of adoption was limited in the first River Basin Management Plans[8]. In early 2018, the European Commission will publish the assessment of the second River Basin Management Plans and the first Flood Risk Management Plans, including an assessment of the adoption of NWRM in both plans.

2. Case studies

Categories of measures

River Restoration measures exhibit a great variety in terms of type, scale and specific processes addressed and thus, several classification approaches are possible. Here, following the guidelines of the Emilia-Romagna (IT) regional authority[9], thirteen categories have been chosen to classify the measures addressing both ecological improvement of riverine environment and reduction of flood risk. The latter is obtained either through direct reconnection of floodplains and consequent restoration of flood retention capacity, or through indirect reconnection, reverting river incision processes; morphological restoration actions can also reduce risks related to river dynamics (which is a component of "flood risk" in a wider accepted meaning). A very brief definition and main aim of each measure is provided below[10]. Within each category, but for one, at least one case study has been selected, mainly from Mediterranean and Alpine countries, to illustrate the specific intervention.

A **Removal / set-back of artificial levees for floodplain reconnection**: removal or set-back of embankments allows to restore a more frequent flooding in the floodplain.

B **Recovery of floodplain by lowering terraces**: riverbed incision can disconnect the floodplain at most flow rates; where restoring a higher riverbed level cannot be

[6] From "COMMUNICATION FROM THE COMMISSION. A Blueprint to Safeguard Europe's Water Resources." COM/2012/0673

[7] From: "European Commission. 2014. EU policy document on Natural Water Retention Measures." By the drafting team of the WFD CIS Working Group Programme of Measures (WG PoM)

[8] NWRM were mentioned in less than a fifth of the first RBMPs. From: "EEA Report 8/2012. European waters – assessment of status and pressures"

[9] Deliberazione della giunta regionale 26 ottobre 2015, 1587 "Linee guida regionali per la riqualificazione integrata dei corsi d'acqua naturali dell'Emilia-Romagna"

[10] A more exhaustive description can be found in the already cited guidelines from Emilia-Romagna or P.Strosser, G.Delacámara, A.Hanus, H.Williams and N.Jaritt. 2015. A guide to support the selection, design and implementation of Natural Water Retention Measures in Europe - Capturing the multiple benefits of nature-based solutions. Final version, April 2015.

obtained, a more natural flooding dynamics can be ensured by lowering the terraces (i.e. the former floodplain); extracted sediments can be reinserted into the river to mitigate the incision process.

C **Afforestation of floodplain to decrease flow velocity**: vegetation increases resistance to flow, slowing it down and increasing retention capacity of the floodplain per unit area, at the same time increasing biodiversity.

D **Increase of diffuse channel roughness**: similar to afforestation, channel roughness slows down instream flow, and can improve ecological conditions through habitat diversification.

E **Reactivation of channel dynamics through the removal of bank protection**: restoration of lateral erosional processes makes available sediment sources to compensate balance deficits, and allows the river to recreate a more natural morphology.

F **Reactivation of channel dynamics through the removal of bank protection, associated with channel widening and/or reconnection of side channels**: similar to the previous measure, includes also an active modification of the river section, in order to fasten and/or improve the expected effects on risk and morphological diversification.

G **Increase of sediment supply from the hillslopes**: increase of sediment load to river reaches subject to sediment deficit can be obtained by recovering or artificially increasing erosional rates on the hillslopes.

H **Removal or structural modification of weirs/check dams and sills**: this action aims at recovering sediment continuity, thus reducing sediment deficit and reactivating deposition and erosion processes that increase habitat diversity.

I **Construction of weirs/sills/other transversal structures for sediment trapping and bed level aggradation**: in case of severe river incision, where riverbed aggradation is considered a priority over longitudinal continuity, the construction of transversal works can be considered a restoration option, mainly associated to other actions to restore connectivity with sediment sources.

J **Addition of sediments in the river channel:** in order to reduce sediment deficit, sediment taken e.g., from reservoirs or other barriers, can be artificially reintroduced in the river channel.

K **Deculverting**: reopening culverted rivers can remove critical sections in relation to flood events and restore at least basic ecological functions.

L **Restoration of channel sinuosity**: through removal of bank protection and usually active reconstruction of a more sinuous or meandering morphology, the average slope of rectified (typically lowland) rivers can be restored, therefore slowing down flows; if a more natural lateral dynamic is allowed, this can ensure habitat improvement.

M **Definition of an erodible corridor**: this measure, consisting of planning and regulatory actions to reduce anthropic use of the floodplain within a corridor where lateral migration of the channel can be allowed. It is included here as it is often a necessary precondition in order to implement active restoration interventions (or to allow passive morphological restoration through natural river dynamics).

List of selected case studies

1. Elbe (DE – Germany): measure A, C;
2. Orbigo (ES – Spain): measures A, E;
3. Leysse (FR – France): measure A;
4. Montone (IT – Italy): measure B;
5. Orbiel (FR – France): measures C, E;
6. Blackwater (GB – Great Britain): measure D, L;
7. Mur (AT – Austria): measure F;
8. Var (FR – France): measure H;
9. Lippe (DE – Germany): measures I, E, D;
10. Drac (FR – France): measure J;
11. Ondaine (FR – France): measure K;
12. Yzeron (FR – France): measures C, L, M;
13. Wertach (DE – Germany): measures A, I, M;

For measure G - increase of sediment supply from the hillslopes – no real scale examples have been identified.

1. Removal/set-back of artificial levees for floodplain reconnection (1): Elbe (DE)

Context

This intervention was part of a larger nature conservation project named “Lenzener Elbtalaue” and of the flood protection strategy “Elbe Flood Protection Action Plan“, which was elaborated in 2002.

Timing and location

The restoration scheme started in 2002 and was completed in 2011. It is located in northern Germany, close to the city of Hamburg.

Aims

The project aimed at restoring the hydrological connectivity between the main channel and its adjacent floodplain, as the old dykes were constructed very close to the river banks. The limited distance between the two dykes (i.e. about 500 meters in a portion of the considered reach) raised also problems concerning flood protection. Other aims of the project were the re-establishment of alluvial forests on former grassland and the development of half-open pasture and meadow landscapes (i.e. periodically inundated grassland).

Measures

Several openings of 200-500 meters along the old levee were created, thus connecting the floodplain to the river in case of high flows, and a new levee was built 1.3 km further away from the river channel, to maintain control over larger floods. In addition, 160 ha of alluvial forest were planted and 85 ha of half-open pasture landscapes were established. In these areas, small stable ponds were also created. These measures required a land re-organization process in order to make areas available, as well as a new land-use practices, which was both promoted through compensation payments.

Figure 1. The area affected by the levee set-back: on the left, before the works; on the right, the openings shown at work during a flood. The red line on the left picture indicates the position of the new levee (sources, left: Christian Damm; right: Nora Künkler).

Monitoring and evaluation

The following aspects were monitored with specific surveys: hydrology, soils, forestry (i.e. assessment of the planted alluvial forests), fish and birds. Local bird populations proved to be a relevant indicator for the ongoing ecological successional processes. The number of resting migratory birds as well as breeding birds increased remarkably, making the site the most densely populated bird sanctuary far beyond the region. The investigations underlined that the changes in habitat quality were mainly influenced by the different flooding duration on the floodplain. The data on fish fauna also shows the ongoing successional processes: two newly created ponds in the floodplain were colonized by eight species, i.e., Bleak (*Alburnus alburnus),* Wels catfish (*Silurus glanis),* European perch (*Perca fluviatilis),* Freshwater bream (*Abramis brama)*; White bream (*Abramis björkna)*; Common dace (*Leuciscus leuciscus)*; Roach (*Rutilus rutilus)* and Pope (*Gymnocephalus cernuus*), three months after the first flooding (Damm, 2013).

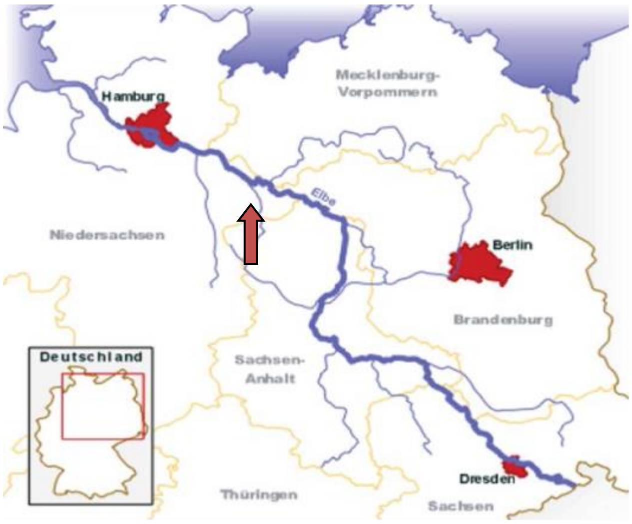

Figure 2. Location of the restored reach, pointed out by a red arrow (modified by Thomas Borchers, German Federal Environmental Ministry).

The prediction of the project's effect on flood peaks was ensured with a substantial modeling exercise and numerical calculations. Specifically, a two-dimensional, hydrodynamic numerical model has been used to compare the situation before and after dyke relocation. The impact of the measures with regards to flood protection could also be directly observed during the extreme flood event that occurred in January 2011, with a reduction of the flood peak between 25 and 35 cm along the restored reach in comparison to the similar flood of 2006.

Public participation and socio-economic information

The project benefitted from an intensive public participation process, in collaboration with a center for environmental education specialized in floodplain ecology. The process of re-allocation of land has taken place in a common process with farmers, in a very constructive way.

The following ones can be identified as the main benefits of the project: (i) reduced flood risk and improved water retention; (ii) increase of biodiversity (mainly fish and bird species); (iii) benefits for the regional development, as the project area got quickly established as a regional attraction on the international Elbe bike trail.

2. Removal / set-back of artificial levees for floodplain reconnection (2): Orbigo (ES)

Context

Increased human activities over the last fifty years altered and impoverished the river Orbigo, resulting in simplified morphology, poor lateral connectivity, loss of longitudinal continuity as well as vegetation simplification and fragmentation. Embankments and channelization did not prevent floods that put housing in small urban stretches under risk, despite their expensive maintenance.

Timing and location

The project was completed in 2013. It is located in northern Spain, close to the city of Leon. Overall, it affected 24 kilometers of river.

Aims

The project aimed at mitigating flood risk, by recovering the connectivity with the floodplain. It also targeted the improvement of the ecological status of the river in the embanked stretch.

Measures

Rock armoring of river banks and earth embankments were removed from more than 13 kilometers of river channels. Some earth embankments were set-back along 5 kilometers of river channels, and other barriers such as groynes were lowered. 10 kilometers of secondary arms were reconnected and/or directly restored. Moreover, a riverbank vegetation buffer was created along 7.2 ha that were reconnected to the river. Other in-channel obstacles, namely weirs, were modified to restore continuity for fish fauna and sediments. The project approach was very different from the experience of the local stakeholders, who were initially reluctant, especially towards expropriation. However, active public participation was set in place, involving stakeholders in 50 meetings during 3 years and eventually facilitating a successful implementation.

Source: Duero River Basin Authority (Confederación Hidrográfica del Duero, CHD)

Figure 3. An artificial levee is lowered to recover lateral connectivity.

Figure 4. River bank protections were also removed along the river: on the left, the situation before the project; on the right, the river is reconnected to its floodplain (source: Duero River Basin Authority – Confederación Hidrográfica del Duero, CHD).

Monitoring and evaluation

Aerial images were collected with drones to compare the river morphology before and after floods. Stakeholder also were interviewed, and provided qualitative assessments of the functioning of the floodplains. A quantitative assessment compared the floods happened during winter 2013 (160 m^3/s), and another in spring 2014 (250 m^3/s), that were successfully contained within the new river configuration, with those of 1995 and 2000, that instead caused serious damages.

Morphological changes are subject to monitoring and evaluation through hydromorphological indicators, but public reports are still to be published. A positive change in the ecological status of the water body has been also recorded.

3. Removal / set-back of artificial levees for floodplain reconnection (3): Leysse (FR)

Figure 5. Construction works: setting back the levee.

Context

The ageing of the levees (150 years) with the resulting increase in risk of failure triggered this project. The levees were constraining the river, effectively turning it into an artificial channel.

Timing and location

The project started was completed in 2006. It is located in alpine France, close to the city of Grenoble. 900 meters were subject to interventions.

Aims

The project aimed at managing the 100-years return period flood within the riverbed. It also aimed at restoring the river that had been constrained for more than 150 years within the artificial levees. The widening of the space allocated to the river benefitted also the ecological corridor along the banks.

Measures

Levees were set back to enlarge the riverbed, and to leave space to the morphological dynamics as well as to the 100-year return period flood. Habitat and vegetation diversification were fostered by inserting small wood obstacles to promote vegetation growth within the river channel. These measures improved the ecological conditions of the river, and improved touristic attractiveness.

Monitoring and evaluation

Ecology, namely macroinvertebrates, were observed to benefit from the project, while were pointing at a degraded state before the intervention. Also fish species increased their abundance and special attention during the monitoring was given to brown trout for its ecological as well as recreational value.

4. Recovery of floodplain by lowering terraces: Montone (IT)

Figure 6. The terrace lowered in the project (source, Regione Emilia Romagna).

Context

This intervention was part of a project at larger scale named “Fiumi puliti” dating back to the ’90s, aiming at riverbeds “maintenance" and flood risk reduction in the eastern part of the Emilia Romagna region, and including the implementation of the “Montone River Natural Park”, in the Municipalities of Forlì and Castrocaro.

Timing and location

The project started in 2004 and was completed in 2007. It is located in northern Italy, close to the city of Forlì. The intervention was carried out in a river reach approximately 1 kilometer long.

Aims

This specific intervention aimed at recovering the natural flood storage capacity by reconnecting the channel to its former floodplain (both public domain and private) which was disconnected due to construction of embankments and long term river incision. As the reversibility of incision was deemed unlikely, it was decided to recreate a new floodplain at lower elevation.

Measures

Within the restored reach the inner (i.e. secondary) embankments were removed and sixteen hectares of floodplain were lowered and reshaped. Fine material with no commercial interest was introduced in the channel during some ordinary flood events, in order to increase the sediment supply downstream and to ensure coastal replenishment.

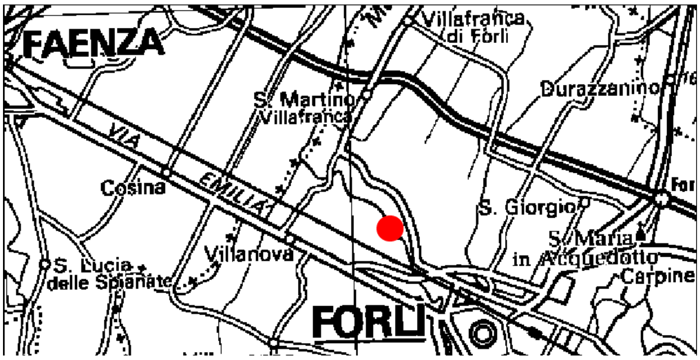

Figure 7. Location of the restored reach along the Montone River pointed out by a red circle (source: Pardolesi, 2012).

Monitoring and evaluation

The prediction of the project’s effect on flood peaks was ensured with a modeling exercise. The interventions were estimated to decrease the water discharge by 3 m^3/s in case of floods with return interval of 100 years. The following aspects were monitored with specific surveys between 2010 and 2011 by a group of public institutions and other associations: hydrology, sediment dynamics, water quality, vegetation and terrestrial and aquatic fauna.

A significant increase of biodiversity was observed compared to adjacent river reaches that were not restored: in the study reach were found 71 species of ground beetles, 36 species of butterflies and 36 breeding bird species. On the other hand, the study reach was classified in moderate status in 2011, according to the Biotic Extended Index based on benthic macroinvertebrate surveys, showing the same quality class that was measured before the restoration interventions (Pardolesi, 2012)[11]. This is not surprising, as this metrics is influenced mainly by physical and chemical water quality.

Figure 8. Sediment recharge during a flood along the Montone River.

[11] Pardolesi F., 2012. Indagine multidisciplinare per monitorare un'area di laminazione delle piene sul fiume Montone a San Tomè – Forlì, in: Trentini G., Monaci M., Goltara A., Comiti F., Gallmetzer W., Mazzorana B. (Eds.). Riqualificazione fluviale e gestione del territorio, Atti 2° Convegno italiano sulla riqualificazione fluviale, Bozen-Bolzano University Press, 135–144

5. Afforestation of floodplain to decrease flow velocity: Orbiel (FR)

Context

The basin of river Orbiel is characterized by short response times of the basin that makes the river prone to fast floods. Bank protections were constructed to address this issue, causing however an impoverishment of the aquatic habitats, lack of riverbanks vegetation and a risk of riverbed incision. Between 12 and 13 November, 1999, a large flood event affected the south of France, causing 35 casualties. Despite the prevention infrastructures, this flood with 50-year return period caused a water level up to 1.2 meters at Conques-sur-Orbiel. Following this event, the local organization in charge of water management decided to restore and enlarge an area already devoted to flood retention.

Timing and location

The project started in 2004, and was completed in 2009. It is located in southern France, close to the city of Toulouse. About 1 kilometer of river shores were affected by the project.

Aims

The project aimed at increasing the flood retention capacity of the floodplain, at the same time improving its ecological conditions.

Measures

One kilometer of the old bank protection was removed to reconnect the river with 15 ha of floodplain, that was also acquired by the local water agency (*Syndicat intercommunal d'aménamegent hydraulique des basin de la Clamoux, de l'Orbiel et du Trabel*). A perpendicular levee was built to delineate the restored floodplain that was purposely designated as a retention area. The combined system results in an "in-line artificial retention area" integrated with the surrounding environment. No other structure exists, especially none that actively controls or reduces the downstream flow during floods. A poplar grove was removed. However, within the area, 5000 other trees were planted to reduce flow velocity during flooding events. It has to be highlighted that unlike most "off-line" artificial retention areas (or "poldering") projects, where river ecological conditions are usually significantly impacted, in case of in-line systems, despite the alteration of water and sediment flows during floods, an overall gain is sometimes possible, if other pressures are removed or mitigated, at the same time.

Monitoring and evaluation

Monitoring is based on the direct experience of floods (in March 2011 a flood similar to the 1999 one caused a level of only 0.6 meters), before the works and after. Although a qualitative improvement can be inferred, no quantitative assessment of ecological conditions after the intervention was apparently carried out.

Figure 9. On the left, the newly constructed levee delineates the area. On the right, 5000 trees are planted in the area to decrease flow velocity during floods. Source: Syndicat intercommunal d'aménagement hydraulique des bassins de la Clamoux, de l'Orbiel et du Trapel (SBCOT)

6. Increase of diffuse channel roughness: Blackwater (GB)

Figure 10. Large Woody Debris (LWD) are inserted in the channel (source, https://restorerivers.eu/wiki/index.php?title=Case_study%3ANew_Forest_LIFE_project).

Context

Starting around 150 years ago, the New Forest rivers, and among them the Blackwater River, were straightened, deepened and widened in order to drain the adjacent wetland for tree planting. Faster flowing rivers led to an increase in erosion of river bed material, reducing the river's ability to support biodiversity, lowering its connection with the floodplain, and in turn leading to the drying out of adjacent wetland features. The project "Sustainable Wetland Restoration in the New Forest" LIFE 3 Project 3[12] aimed at improving the ecological conditions of wetland habitats of the catchment by increasing habitat diversity.

Timing and location

The project started in 2003, and was completed in 2006. It is located in southern England, close to the city of Southampton. The works spanned over 3.7 kilometers of river channel.

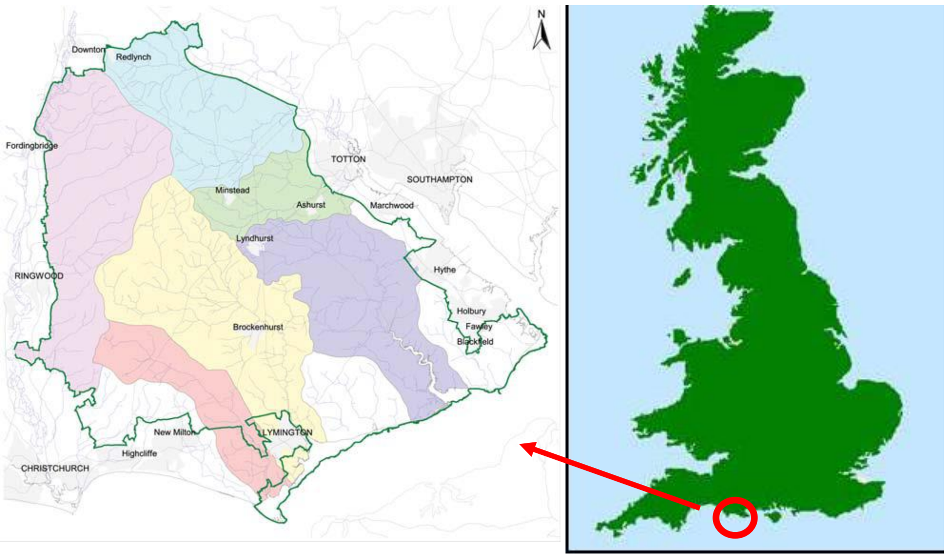

Figure 11. Location of Blackwater River, in southern England (source, Layman's report of "Sustainable Wetland Restoration in the New Forest" LIFE 3 Project).

[12] http://www.newforestlife.org.uk/

Aims

One of the key objectives of the project was to restore incised watercourses to a more natural condition. Streams were reconnected with their floodplains stimulating the regeneration of adjacent riverine woodlands. The project targeted the creation of habitats for fish and macroinvertebrates, and also aimed at increasing the resistance to water flow, thus the frequency of floodplain inundation events, delaying the flood peak downstream.

Measures

The restoration of the Blackwater included the introduction of in-stream large woody debris (LWD) creating habitats for invertebrates and fish, and the reinstatement of many original meanders, which used to exist before the tributaries were artificially straightened. Riverbed levels were also raised by up to 1 m by in-filling using locally sourced sand and gravel.

Monitoring and evaluation

Topographical, hydrological and geomorphological monitoring were carried out. Post-restoration monitoring confirmed the intended increase in overbank flooding, and associated erosion and deposition over the floodplain. Debris dams also developed, creating diverse physical habitat both within the channel and on the floodplain. Moreover, Blackwater stage data show a definite decrease in magnitude of the peak events in downstream gauging stations which suggests that the restoration has been successful.

As regards ecological monitoring, benthic macroinvertebrate surveys showed significant differences between invertebrate communities of degraded, channelized reaches, and those found in the restored reach. Fish surveys were also carried out in order to allow comparison between the channelized and the restored reach. These surveys confirmed that his type of habitat restoration positively affected both the spatial distribution and abundance of species of key importance, such as River lamprey (*Lampetra fluviatilis*) and Bullhead (*Cottus gobio*).

Figure 12. Blackwater River before (left) and after (right) the restoration actions (source, Hydrological Report of "Sustainable Wetland Restoration in the New Forest" LIFE 3 Project).

Public participation

The project "Sustainable Wetland Restoration in the New Forest" LIFE 3 Project has successfully raised public awareness of the importance of wetlands and their restoration. Several high profile events have been held, including a launch event in December 2002, and two end of project events during June 2006. Activities for the general public were carried out at the restored sites, with children's activities and guided walks.

7. Reactivation of channel dynamics through the removal of bank protection, associated with channel widening and reconnection of side channels: Mur (AT)

Figure 13. An abandoned channel is reshaped, and reconnected to the main channel at Thalheim. Source: Laymans report on "LIFE-UPPER MUR mur[er]leben 2003-2016".

Context

Systematic river regulation, beginning at the end of the 19th century, caused substantial changes in the morphology of the Mur River. Channel morphology was formerly complex and characterized by the presence of secondary channels, shallow zones, gravel bars. As a result of regulation, the River Mur's dynamic was substantially limited along extended sections, with secondary channels cut off and large areas drained to make them available for agriculture. Moreover, many hydropower plants were built, strongly impacting sediment transport. These changes led to disconnection of the Mur River from the adjacent floodplains and caused a substantial reduction of valuable habitats for fish, amphibians and birds. In the 70's large national programmes foresaw the restoration of water quality, while two LIFE projects "Murerleben I and II" were carried out between 2003 and 2016.

Timing and location

The first project started in 2003, and the last was completed in 2016. The interventions were located in eastern Austria, close to the city of Graz.

Aims

The two LIFE projects "Murerleben I and II" aimed at (i) improving the aquatic habitats, (ii) protecting the habitat of endangered species, such as the Danube salmon (*Hucho hucho*), (iii) recovering the natural hydromorphological dynamics and (iv) improving passive flood protection by reverting the incision process and, thus, increasing the flood retention capacity of the floodplain.

Measures

Seven secondary channels and abandoned tributaries were either restored or created anew, removing bank protections and embankments. 17 hectares of former floodplain were acquired and used for the reactivation of the abandoned channels. In addition, more than 90 km of river were made fish-passable.

Monitoring and evaluation

Biological monitoring showed that the newly created habitats were used by juvenile fish and served as spawning sites for amphibians, among them the endangered Italian crested newt (*Triturus carnifex*) and the Yellow-bellied toad (*Bombina variegata*). Moreover, the hydrological regime in the floodplains improved the conditions suitable for rejuvenation of riparian vegetation. As regards morphological monitoring, the bed level within the restored reach raised and the observed riverbank erosion indicates further channel widening. No data has been made available so far about monitoring and evaluation of flood risk mitigation.

Public participation

Local communities were involved in the interventions of restoration through school projects and the participation to festival and public events.

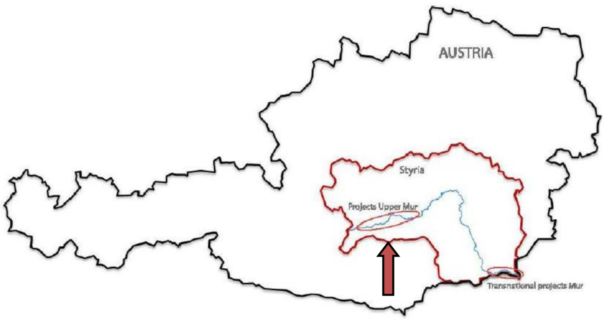

Figure 14. Location of the restored segment of the Mur River pointed out by a red arrow.

8. Removal or structural modification of weirs/check dams and sills: Var (FR)

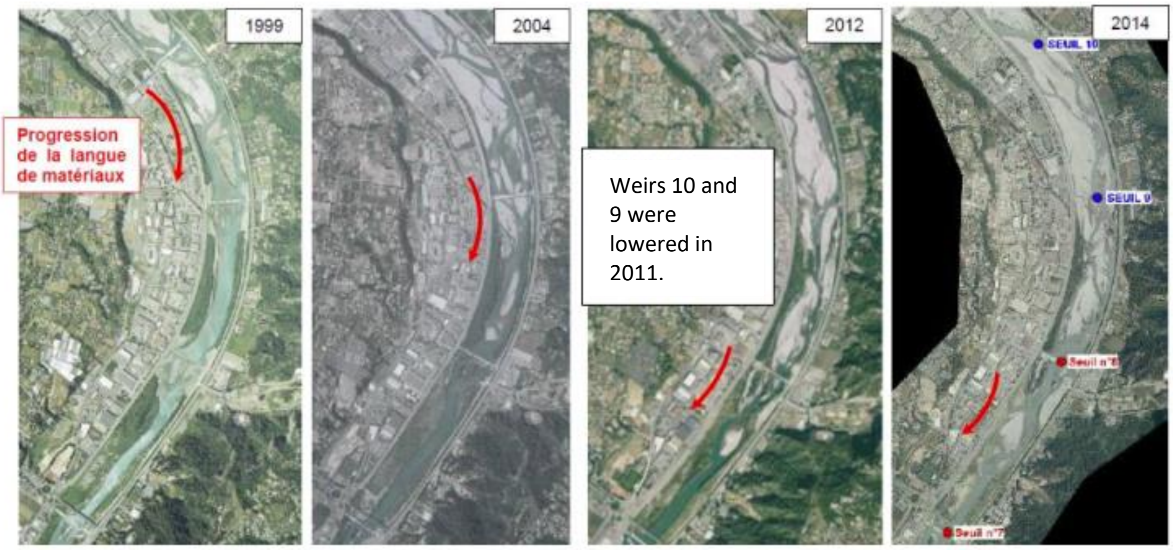

Figure 15. Advancement of braided channels morphology as weirs are lowered on the Var River.

Context

Starting in 1967, a system of weirs was built on the Var to consolidate the riverbed, and to control incision, due to previous instream sand mining activities, now no longer active. The weirs reached the desired aggradation effect, but in the medium term the associated flood risk increased too much and sediment transport downstream needed to be increased.

Timing and location

The project started in 2011, and was completed by 2012. It is located in southern France, close to the city of Nice. The intervention here depicted spans over approximately two kilometers, while the weirs system covers 10 km. There are other 7 weirs downstream that are planned to be removed by 2021 – the river already destroyed one of them.

Aims

The project aimed at increasing the sediment transport, recovering sediment connectivity, thus allowing the recovery of dynamic braided channels.

Measures

In the intervention analyzed here two weirs were lowered by 1.5 and 2 meters, respectively. River bank protections were also consolidated. The vegetation previously covering the dormant floodplains within the riverbanks was cleared to increase sediment mobility.

Monitoring and evaluation

Progress of morphological evolution is monitored via LiDAR images (2009, 2011, and 2013). A more comprehensive monitoring program is sketched, given that part of the area is included in a Natura

2000 site. In 2007, a groundwater measuring network was installed to improve the modeling of the aquifer system.

9. Construction of weirs/sills/other transversal structures for sediment trapping and bed level aggradation: Lippe (DE)

Figure 16. Large Woody Debris were put in place to initiate natural dynamics (source, M. Bunzel-Drüke).

Context

The state of Nordrhein-Westfalen started in 1990 a restoration programme called "Gewässeraueprogramm" (river floodplain programme) that included a project on the Lippe River in the area called *"Klostermersch"* between the villages of Benninghausen and Eickelborn. In this reach both banks were almost completely fixed by bank protections and the floodplain was disconnected from the channel before the interventions of restoration, as a significant process of incision occurred during the 20th century.

Timing and location

The project started in 1996, and was completed in 1997. It is located in north-western Germany, close to the city of Dortmund. The length of the restored reach is about 2 kilometers.

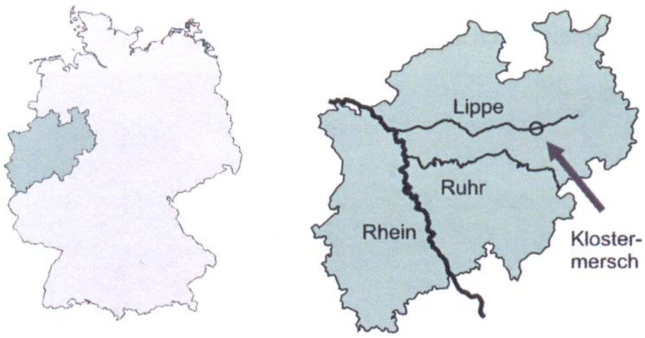

Figure 17. Location of Lippe River in north-western Germany (source, Lippeauenprogramm).

Aims

The project aimed at controlling incision in the main channel and restoring the hydrological connectivity between the main channel and its former adjacent floodplain. Another aim of this project was to improve passive flood protection by reverting the incision process and, thus, increasing the flood retention capacity of the floodplain.

Measures

In this intervention, sediments were directly added into the river channel, until it was raised by two meters, and therefore reconnected with its floodplain. A ramp was built at the downstream end of the restored reach to prevent channel incision and several Large Woody Debris (LWD) were introduced in the main channel to initiate natural channel dynamics and to increase local depth variability. Bank protection and fixations were also removed, widening the active channel from 13 to 45 meters. Floodplain use was restricted to extensive grazing to allow for natural succession of floodplain vegetation.

Figure 18. Lippe River before (left) and after (right) the restoration actions (source, J. Drüke).

Monitoring and evaluation

No data has been made available so far about monitoring and evaluation of flood risk mitigation.
Biological monitoring showed that species composition was still adjusting to the changing morphological conditions several years after implementation of the project. Fish were monitored using a Before / After Impact / Control design (BACI). Most fish naturally occurring in the Lippe were already present prior to the restoration but abundance of many species did increase in the restored reach. Solely the abundance of eels was lower in the restored reach compared to the control reach since eels used riprap as cover. On the floodplain, amphibians recovered more slowly compared to fish, probably due to the lower re-colonization potential.
Morphological evolution was monitored from 1997 until 2000, showing a significant change in channel morphology, an increase in depth variability and a positive sediment balance.
Moreover, within the FP7 REFORM project, the MQI (Morphological Quality Index) and MQIm (Morphological Quality Index for monitoring) (Rinaldi et al., 2017) were calculated in the restored reach, considering the situation before and after the interventions. The restoration caused a marked improvement of the MQI value (i.e. from 0.55 to 0.74), with a change from moderate to good morphological status. The application of the MQIm underlined also a significant improvement of the morphological conditions before and after the interventions of restoration, as the MQIm values varied from 0.66 to 0.82 (Belletti et al., 2017).

10. Addition of sediments in the river channel: Drac (FR)

Figure 19. The Drac in the restored reach (October 2017, picture by Bruno Boz).

Context

In 2000, a scientific study highlighted a problem of incision in the Drac riverbed, caused by the intense gravel extraction started in 1960, and eventually ended in 2012. The incision reached up to few meters, eventually reaching a clay layer that further accelerated the incision. Along with the riverbed, the water table lowered as well, altering the riparian forest. The new clay substrate substituting the gravel one caused further alteration of the aquatic habitats, allowing an expansion of clay outcrops. Moreover, the stability of the dam at the Champsaur leisure center, a lake used for recreation and fishing, was compromised, causing significant risk.

Timing and location

The project started in November 2013, and was completed by June 2014. It is located in southern France, close to the city of Grenoble. The project affected 4 km of river.

Aims

The project aimed at reverting the incision that threatened the riverbanks with respect to structural failures of the Champsaur dam. This goal was coupled with the restoration of morphological dynamics of the river, particularly by developing a braided channel morphology similar to the condition of Drac before the incision phase. Moreover, the project targeted sediments continuity, and the lateral reconnection of tributaries.

Measures

450 000 cubic meters of gravel were recovered, mainly from the terraced alluvial plain of the Drac, and added to the river channel. The altimetric profile prior to extraction was in this way reconstructed.

A weir was built at the downstream end of the intervention to fix the riverbed height. The weir features a passage for fish and one for canoes.

Monitoring and evaluation

LiDAR images were taken from 2009 to 2015, and several other pieces of information describing the situation prior the intervention, ranging from morphodynamics, to habitats and aquatic fauna. The project establishes a 10-year monitoring program on morphology and ecology, but final results are not available yet (the restoration works finished in April, 2014). However, the first morphologically relevant flood (15/11/2015) triggered the development of a system of braided channels. Moreover, flagship species such as the Common kingfisher (*Alcedo atthis*), were rapidly seen to come back to the area, while the French National Agency for Water and Aquatic Environments (ONEMA) identified about thirty spawning spots for Salmonidae on the 4 km of the project, where before the works only five were identified. Detailed monitoring and evaluation, including the assessment of ecosystem services associated to the restoration project, are foreseen in the framework of the HyMoCARES project[13].

Figure 20. On the left panel, aerial view on the single channel Drac prior the 2013 intervention; the Champsaur dam can be recognized in the bottom right corner. The river flows towards the top of the picture. On the right panel, the same area is covered.

[13] www.alpine-space.eu/hymocares

11. Deculverting: Ondaine (FR)

Figure 21. A view of the deculverting works: on top, the situation prior interventions; below, the reopened channel is pictured in 2011. Source: Saint'Etienne metropole.

Context

The Ondaine River had been constrained in a culvert since the end of the 19th century for a length of 500 meters, in the city of Chambon Feugerolles. Towards the end of the '90s, the tunnel ceiling developed signs of failures after flooding events. The development of an urban restoration scheme aiming to transforming an old industrial area into a residential one was an opportunity for the restoration of the river. A river contract was also established.

Timing and location

The project was completed in 2010. It is located in southern France, close to the city of Saint-Etienne.

Aims

The project aimed to restore a more natural ecosystem, mainly in order to improve the landscape and recreational value of the Ondaine. A river that had been concealed over the last century was going to be accessible again by citizens. At the same time, eliminating the risk of tunnel ceiling failure would also eliminate the corresponding flood risk.

Measures

90 000 cubic meters of material was removed for deculverting 485 meters of river, eliminating the tunnel. The new riverbed was shaped, and stabilized, partly with bioengineering techniques, ensuring the establishment of riparian vegetation, for a total of 1.2 km of works. The new channel was designed to carry the centennial flood.

Monitoring and evaluation

No quantitative assessment of the effects of the restoration scheme has been made available so far.

Figure 22 The reopening works at the Ondaine river

Figure 23 The restored stretch just upstream the deculverted section

12. Restoration of channel sinuosity: Yzeron (FR)

Figure 24. A section of the works completed on the Yzeron, at Charbonniéres-les-Bains. Source: Sagyrc, Syndicat intercommunal du bassin de l'Yzeron.

Context

Increasing urbanization in the recent past close to the river exposed people and properties to flood risk. A significant flood happened in 1989, after which an initial program focusing on hydraulic aspects of the problem was set. However, a sequence of floods in 2003, 2005, 2008, and 2009 generated additional damages, adding up to €85 million. These events finally triggered an integrated response, with a program of works covering the entire basin. Among the completed ones, we here analyze the intervention in the town of Charbonniéres-les-Bains.

Timing and location

The project started in 2012, and was completed by summer 2013. It is located in southern France, close to the city of Lyon.

Aims

The main aim was to enlarge the river so that it can carry the centennial flood, at the same time ensuring ecological improvement and facilitating public access to the river.

Measures

Enlargement of the riverbed was combined to reshaping of the river aimed at increasing channel sinuosity. A footbridge to improve recreational opportunities was constructed to replace the two destroyed by the flood in 2008.

Monitoring and evaluation

Two years after work conclusion, the river evolution was under inspection, with photographic records. However, monitoring results will be available after the entire program completion, due in 2019. Meanwhile, the river contract *Yzeron Vif* is enforcing the measurement of a set of indicators.

13. Definition of an erodible corridor: Wertach (DE)

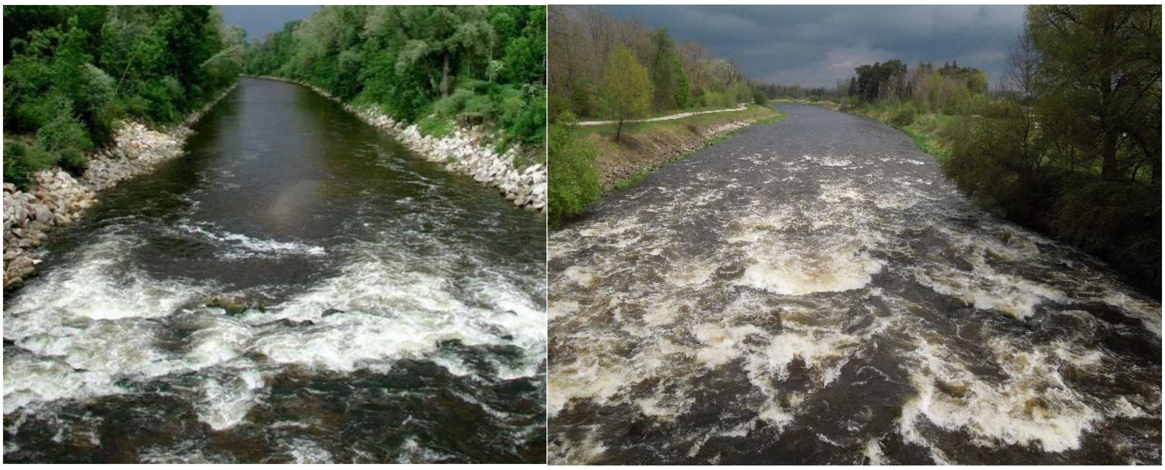

Figure 25. Wertach River from the Wertachbrücke before (left) and after (right) the restoration actions (sources, above: http://www.wwa-don.bayern.de/hochwasser/hochwasserschutzprojekte/wertachvital/; below, author: Dr. Martin Pusch, IGB).

Context

The Wertach River was straightened during the 20th century, with subsequent construction of a series of dams, reservoirs and hydropower plants upstream. In addition, many weirs were built to stabilize the river channel. As a result, channel width decreased significantly, while channel slope increased. A process of incision occurred and the river bed lowered by several meters. As an undesired effect of river channelization, the water retention of the river was greatly lost, so that the flood risk has risen. In addition, also the ecological integrity of former river floodplains has been affected by channel incision. Fragmentation of the river by hydropower dams, and hydropeaking operation of hydropower plants resulted in a severe reduction of fish density and diversity. Especially, formerly typical, abundant and economically valuable fish species as Danube salmon (*Hucho hucho*) and Grayling (*Thymallus thymallus*) have mostly disappeared.

Timing and location

The length of the restored reach, located in southern Germany, close to the city of Augsburg, is about 14 kilometers. The entire segment was divided in three sub-reaches (i.e. Wertach vital I, II and III). Integrated interventions of restoration were carried out mainly in the sub-reach Wertach vital I. The project started in 2000 and the interventions of Wertach vital I were completed in 2009.

Figure 26. Location of Wertach River in southern Germany. In orange, the restored reach of the Wertach River. (Graphics: M. Carolli, IGB).

Aims

A multi-targeted restoration project, called “Wertach vital”, has been initiated by the water management agency (Wasserwirtschaftsamt). The aims of this project are (i) to mitigate channel incision, (ii) to improve the ecological conditions, and (iii) to improve the access to the river for recreational activities. Moreover, the nearby inhabitants of the Wertach River have to be reliably secured from destructive floods.

Measures

In the interventions, several bank protections were removed, bank slope was flattened and the river channel was widened. In addition, levees were set-back in order to create a potential erodible corridor in the upstream portion of the restored reach. The longitudinal continuity was also improved through the building of fish ladders at the “Ackermann” weir and the “Inningen” barrage, while three ramps were built to stabilize the river bed and to prevent further incision.

Monitoring and evaluation

Biological monitoring showed that fish populations in the restored reach increased in terms of both diversity and abundance. Several fish species such as Grayling (*Thymallus thymallus*), Barbel (*Barbus barbus*), Eurasian minnow (*Phoxinus phoxinus*), and Schneider (*Alburnoides bipunctatus*) colonized the restored reach. Other relevant faunistic observations are those of birds, Ringed plover (*Charadrius hiaticula*) and Common snipe (*Gallinago gallinago*), and of the dragonfly Small pincertail (*Onychogomphus forcipatus*).

No data are currently available about monitoring and evaluation of flood protection aspects. Some surveys will be carried out in the context of the HYMOCARES project.

Public participation

The project was accompanied by extensive communication actions with local residents and stakeholders, including the collection of opinions by questionnaires.

3. Information sources

The screening of the case studies is mainly based on the following sources. Some of the documents are not available in English.

- Elbe (DE): Case study report on "Elbe dyke relocation (Lenzen)" from Natural Water Retention Measures (NWRM); Damm C., 2013; *"Ecological restoration and dike relocation on the river Elbe, Germany"*. Scientific Annals of the Danube Delta Institute, 19, 79 – 86. Links: http://nwrm.eu/case-study/dyke-relocation-river-elbe-near-lenzen-germany; http://www.naturschutzgrossprojekt-lenzen.de/seiten_tgf/ak_set.html.
- Orbigo (ES): "*Proyecto de mejora del estado ecológico del río Órbigo, Tramo I (León). Clave: 02.434-229/2111 Versión Actualizada en noviembre de 2009*".
- Montone (IT): "*Indagine multidisciplinare per monitorare un'area di laminazione delle piene sul fiume Montone a San Tomè, Forlì*", by Fausto Pardolesi at "*2° Convegno italiano sulla riqualificazione fluviale*", Bozen 6 - 8 November 2012. Pardolesi F., 2012. *Indagine multidisciplinare per monitorare un'area di laminazione delle piene sul fiume Montone a San Tomè – Forlì*, in: Trentini G., Monaci M., Goltara A., Comiti F., Gallmetzer W., Mazzorana B. (Eds.). Riqualificazione fluviale e gestione del territorio, Atti 2° Convegno italiano sulla riqualificazione fluviale, Bozen-Bolzano University Press, 135–144. Link: https://restorerivers.eu/wiki/index.php?title=Case_study%3AFloodplain_recreation_on_the_Montone_River_at_San_Tom%C3%A8_(Forl%C3%AC).
- Orbiel (FR): *"Restauration du champ d'expansion des crues de l'Orbiel par suppression des contraintes latérales, à Limousis"* by ONEMA. Link: http://www.onema.fr/sites/default/files/pdf/rex_r5_Orbiel_v2BD.pdf.
- Blackwater (GB): "*Sustainable Wetland Restoration in the New Forest*" LIFE 3 Project. Links: https://restorerivers.eu/wiki/index.php?title=Case_study%3ANew_Forest_LIFE_project; http://www.newforestlife.org.uk/.
- Mur (AT): "*LIFE-Upper Mur mur[er]leben 2003-2016. Inner-alpine river basin management on the upper River Mur*". Link: http://www.murerleben.at.
- Var (FR): "*Retour au faciès méditerranéen du fleuve Var – Abaissement des seuils*" at *Journée technique GEMAPI*, Cadenet, 18 juin 2015.
- Lippe (DE): "*Lippeauenprogramm – Die Klostermersch. Ein Fluss erobert seine Aue zurück*". Link: http://wiki.reformrivers.eu/index.php/Lippeaue_Klostermersch.
- Drac (FR): Claude Michelot, Fréderic Laval, Burgeap "*Restauration du lit du Drac amont par recharge sédimentaire", at Etats généraux "L'eau en montagne*", Megève (FR) – 8, 9, 10, October 2014.
- Ondaine (FR): "*Découverte et réhabilitation de l'Ondaine au Chambon Feugerolles*". Link: http://www.riviererhonealpes.org/sites/default/files/media/documents/journees_techniques/5-rehabilitation_de_londaine_g4.pdf.

- Yzeron (FR): SagYrc "*Dossier de concertation sur les projets de barrages secs*". Link: https://www.riviere-yzeron.fr/wp-content/uploads/2016/03/concertation-sagyrc-avril2016-web.pdf.
- Leysse (FR): "*La restauration de la confluence Leysse-Hyères*". Link: http://www.chambery-bauges-metropole.fr/916-la-restauration-de-la-confluence-leysse-hyeres.htm.
- Wertach (DE). Link: www.wwa-don.bayern.de/ hochwasser/hochwasserschutzprojekte/ wertachvital/.

Reports including information on river restoration works for flood risk mitigation

- Technical portal on managing flood risk and river restoration works from the Agence Française pour la Biodiversité, including several useful *Retours d'expériences* [ex-post assessments of case studies].
  http://www.onema.fr/gestion-des-risques-d-inondation-et-restauration-des-cours-d-eau.
- The manual "*Pour une nouvelle gestion des rivières*" [For a new management of rivers], especially the second volume with restoration examples.
  http://www.eaurmc.fr/espace-dinformation/guides-acteurs-de-leau/agir-sur-lhydromorphologie-des-milieux-aquatiques.html?eID=dam_frontend_push&docID=4219.
- The series of research reports on "Working with natural processes to reduce flood risk" by the UK Environmental Agency, published on 31st Oct 2017.
  https://www.gov.uk/government/publications/working-with-natural-processes-to-reduce-flood-risk.

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Palmer, M.A., Menninger, H.L., Bernhardt, E., 2010. River restoration, habitat heterogeneity and biodiversity: a failure of theory or practice?. *Freshwater biology,* 55(s1), 205-222.

Rinaldi, M., Belletti, B., Bussettini, M., Comiti, F., Golfieri, B., Lastoria, B., Marchese, E., Nardi, L., Surian, N., 2017. New tools for the hydromorphological assessment and monitoring of European streams. *Journal of Environmental Management*, 202 (2): 363-378.

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