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Restoration of fish passage and results of a master plan established for the Ruhr River Basin

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ABSTRACT: According to the central aim of the European Water Framework Directive, the ecological and chemical conditions will be primary quality elements in future for surface waters. Population diversity and abundance of fish and macroinvertebrates is decisive in aiming at the good ecological status in surface water bodies,. Free passage in river systems is a prerequisite to allow the natural migration of fish and other aquatic organisms. In order to point out potentialities for the Ruhr River Basin a study was commissioned to develop a master plan for river continuity restoration. This study was complemented by investigations into the sediments in the rivers, in order to identify river sections or tributaries which presumably provide a suitable habitat for the successful reproduction of salmonides. The master plan illustrates the inherent problems of projects aimed at the restoration of fish migration in surface waters which are strongly affected by anthropogenic modifications. The results obtained can be transferred to other river basins with similar conditions.

KEYWORDS: European Water Framework Directive, river basin management, river restoration, river continuity, fish passage, fishway, hyporheic interstitial, master plan

1 Introduction

The European Water Framework Directive (WFD) [1] came into force in December 2000. Its central goal is the protection and sustainable management of the aquatic ecosystems. According to the new provisions, the quality of surface waters is assessed by biological and chemical elements, as well as various hydromorphological parameters supporting the biological elements. Corresponding to this approach, which combines environmental quality standards and fixed emission limit values, the ecological status of surface water bodies will be derived chiefly from biological quality elements, such as the composition and abundance (and age structure) of the fish and benthic invertebrate fauna. Thus, river continuity respectively free passage is a key objective in river basin management, in order to permit natural, unimpeded migration of fish and other aquatic organisms.

However, due to multiple, sometimes even conflicting water uses, many rivers all over the world have seen severe anthropogenic modifications. The Ruhr River, a tributary of the Rhine River, located in the German state of North-Rhine Westphalia (NRW), has been particularly affected by such changes. The industrial development in the nineteenth and twentieth century with its rapidly expanding urban environment has created the Ruhr District which is one of the largest conurbations in Europe. As a result of the urban sprawl and the booming industrial activities, water soon became a matter of common concern which led to the foundation of water associations tailored to the specific needs of individual river basins. Since then these associations (one of which is the

Ruhrverband (Ruhr River Association) founded, under special acts, in 1913) have been responsible for all water management-related issues. From the beginning, the activities of the Ruhrverband have been aimed at an integrated, holistic, yet a still strongly water quantity and water quality-oriented approach to river basin management.

In the face of the severe water and wastewater problems prevailing at the beginning of the twentieth century, it was decided that the Ruhr River should serve as source for both drinking and industrial water supply for the region, which today, as in the past, is one of the most densely populated in Europe. Within the framework of existing legislation, the Ruhrverband currently operates a system of 8 reservoirs, around 80 wastewater treatment plants and more than 500 stormwater detention facilities. Moreover, the Ruhr River is used for hydropower generation, and in summer it comes alive with passenger and sailing boats as a favourite recreation area for the population. Thus, to date, there are numerous dams, weirs, locks and hydropower plants interrupting the river continuum of the Ruhr River and its tributaries and therewith hindering or delaying migrations and other movements of aquatic organisms.

2 General aspects and aims of the master plan

Annex V of the WFD contains the normative definitions of ecological status classification specifying biological, hydromorphological and physico-chemical elements. The goal of a "good ecological status", as defined in the WFD for the fish fauna, will be achieved if there are only slight changes in the composition and abundance of the aquatic fauna from the type-specific communities. As a result of the fish fauna inventory within the scope of the Rhine River Basin management plan according to the WFD, 32 % of the entire river courses in the Ruhr River (sub-)basin were identified as "being at risk", 47 % as "possibly being at risk" and merely 21 % as "not being at risk" of failing the environmental quality objectives [9].

Due to the fact that population diversity and abundance of fish and macroinvertebrates are decisive preconditions for a good ecological status of surface waters, and as almost all aquatic organisms in rivers are known to migrate between different locations of their habitat, it is essential to allow their migration and ensure free passage in river systems,. Within the Ruhr River Basin the type-specific, i.e. potentially natural fish fauna comprises 38 different fish species. At present 30 fish species inhabit the Ruhr River and its tributaries; previously native diadromous fish species, such as salmon, sea-run trout, shad and lamprey are "missing" [6]. River continuity is particularly vital for the diadromous fish species, as they need to return to their spawning grounds located within the grayling zones of rivers and their tributaries (Fig. 2). As the migrating activities, e.g. those of salmon, take place within a period of about two months, it is furthermore important for the fish to reach their spawning grounds as fast as possible, in order to assure a persistent population development.

Several efforts have been undertaken over the last years to improve the situation. For example the removal of disused old weirs, as also to build fishways at weirs still in service. A number of fishways have already been built in the Ruhr River Basin. Almost all of them however were implemented as isolated projects, resulting in no further investigations as to whether and how, these specific measures influenced or improved the overall aquatic situation. This though might well have affected the project's configuration or constructional features. Neither did the expected effectiveness or efficiency of

the fishways play a major role for priority setting or in the decision-making process.

Approximately 1,300 weirs (272 at hydropower plants) were recorded within the 4,485 km¸ large catchment of the Ruhr River Basin (Fig. 1). Up to now, only 67 out of this large number of barriers are equipped with fishways; some further 960 are assessed as "not passable" or "passage restricted" [6]. No less than 18 large weirs have to be passed in order to reach the mouth of the Lenne River, which is located 94 km upstream of the Ruhr mouth into the Rhine. There are 13 hydropower plants with heads of up to 8.75 m and discharges of up to 145 mł/s. Nine of these 18 weirs already have functioning fishways, two fishways are presently being built, and another five are being planned. The 128-km-long Lenne River, the most important tributary of the Ruhr, is dammed at 53 sites for small-scale hydropower generation and/or for water abstraction; the heads vary between 0.30 and 5.50 m. The existing hydropower stations are predominantly plants with diversion channels; the main flow is extracted from the river at an intake structure close to a weir. Accordingly almost 20 % (25.9 km) of the entire river course and 37.5 % in the lower and middle reaches of the Lenne (with a length of 110 km) are stretches with (minimum) residual flows. Only 12 of the 53 Lenne weirs mentioned above are equipped with fishways, many of which were found to be malfunctioning [2].

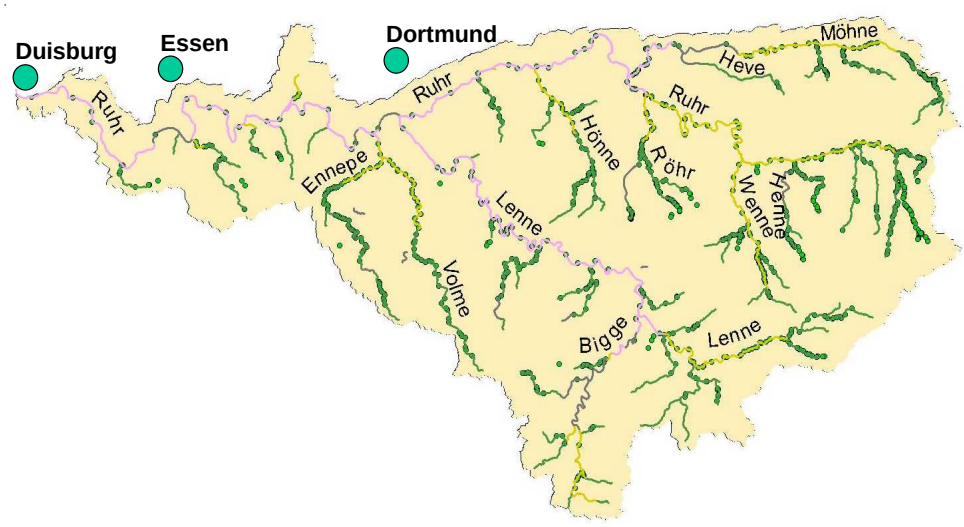

Fig. 1: Number and location of existing barrages within the Ruhr River Basin (in January 2003)

There are two ways to restore fish passage at barriers: remove the weirs or install fish passage facilities (fishways). Against this background and relying on its longstanding experience in river basin water management, the Ruhrverband deems it advisable to make a holistic approach for all measures geared at restoring the longitudinal and lateral river continuity as well as the vertical (hyporheic) connectivity. Moreover it recognises the urgent need for the development of a specific supra-regional concept for up- and downstream fish passage restoration. Considering the substantial capital requirements as well as the special conditions prevailing along the Ruhr River, it is necessary to concentrate all available funds into a spatially and temporally optimised programme.

3 Working steps of the master plan

In order to develop a master plan for continuity restoration in the Ruhr River Basin a study [6] was commissioned. Its three major steps were

- to establish the basic requirements for restoring up- and downstream fish passage,
- to determine potential spawning and nursery habitats as well as the migration corridors for reaching them and
- to enable a practicable step by step procedure in time and space with optimum utilisation of the available funds.

At first, an assessment of the rivers in the Ruhr Basin was carried out, using the river zoning model according to *Huet* [3] and *Illies* [4] (Fig. 2). According to this zoning plan, the upper reaches of the Ruhr River are rated as trout zone and the following 60 km as grayling zone. The 130 km long river stretch below the mouth of the Roehr River, is classified as barbel zone, whereas the last 10 km down to the River mouth into the Rhine can be assigned to the bream zone. The five impounded lakes in the lower and middle Ruhr reaches play a special role as they do not quite fit into the classical zoning model for rivers and streams. These heavily modified water bodies were not categorised under specific ichthyo-biological aspects. The Lenne River (seen from the point where it flows into the Ruhr River) divides into a ~80-km-barbel zone, a ~25-km-grayling zone and a ~25-km-trout zone.

To determine the varying habitat requirements under ichthyo-ecological aspects, the fish fauna was divided into ecological guilds: catadromous, anadromous, rheophilous, limnophilous, and indifferent species. In principle, the master plan considers all existing and potentially natural species (i.e. type-specific communities according to the WFD) without any special focus on a characteristic fish species or guild.

All available databases and information, such as the fish species register of NRW and reports on historic fish species distribution, were evaluated for stocktaking of the existing as well as the potentially natural fish fauna (see chap. 2).

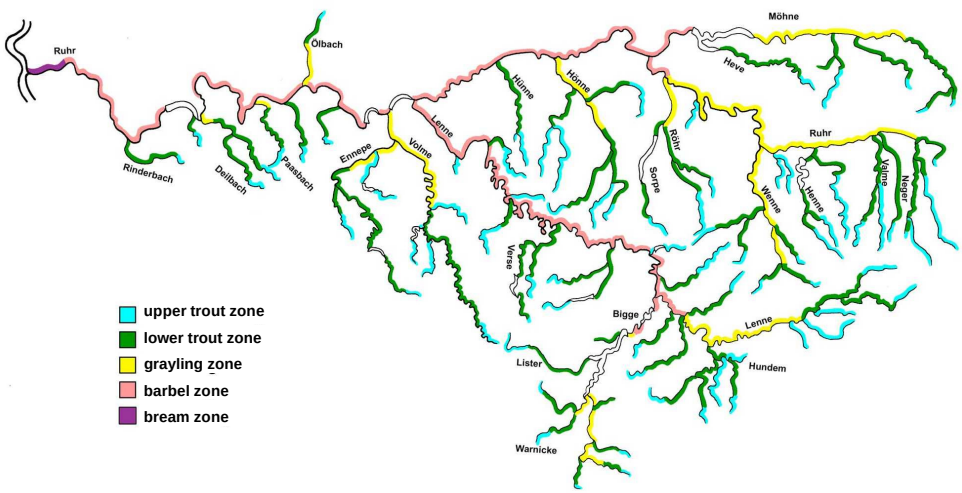

Fig. 2: River zones of the water bodies in the Ruhr River Basin

For a reliable habitat mapping, based on these stocktaking results and to comply with the short migration time of some fish species, it is necessary to localise readily accessible habitats of good quality. A preliminary check of the water bodies within the grayling zones of the Ruhr Basin, excluding all backwater reaches, revealed that there are sufficient potential spawning habitats in the Ruhr River (above the mouth of the Lenne), in the Lenne River as well as in the Volme River and Ennepe River (Fig. 3). Reaches upstream of the large reservoirs were left aside in this first approach, as they appear to be inaccessible for migratory fish in the short or medium term, although the reservoir inflows and their tributaries do represent good spawning habitats.

In order to verify their suitability as spawning habitats, a comprehensive investigation into the sediment and the gravel interstitial system of potential habitat areas had to be carried out. Analyses of the river bottom were undertaken at 43 points in the Ruhr catchment, particularly in the grayling zone. Samples of approximately 20 litres of sediment each were extracted from a depth of 20 to 30 cm in the river bed, along the axis of the main flow in the transition zone of pool-riffle-sequences. The samples were wet-sieved and examined for particle-size distribution. To properly assess the samples, they were compared to a series of reference samples taken from various other rivers (e.g. the Allier in the Loire Basin (France) and the Ahr, Agger, Broel or Nette (Germany)), all of which are well-known spawning grounds for salmon or lamprey. Favourable spawning grounds were found to exist in particular in the rivers Volme, Roehr, in the upper Ruhr and upper Lenne. Hence to make them accessible primarily as spawning ground for gravel-spawning fish species, priority should be given to conservation and restoration of these river stretches.

However, not only the restoration of the river continuity, but also the quality of the gravel interstitial system (hyporheic interstitial) as potential spawning habitat is decisive for a successful re-colonisation of fish populations and the return of migratory fish species into river sections previously either inaccessible or inhabitable. Under natural conditions, a continuous exchange process takes place between the hyporheic zone and the river flow through a multitude of hydraulic processes and ensures a sufficient oxygen supply. A minimum oxy-

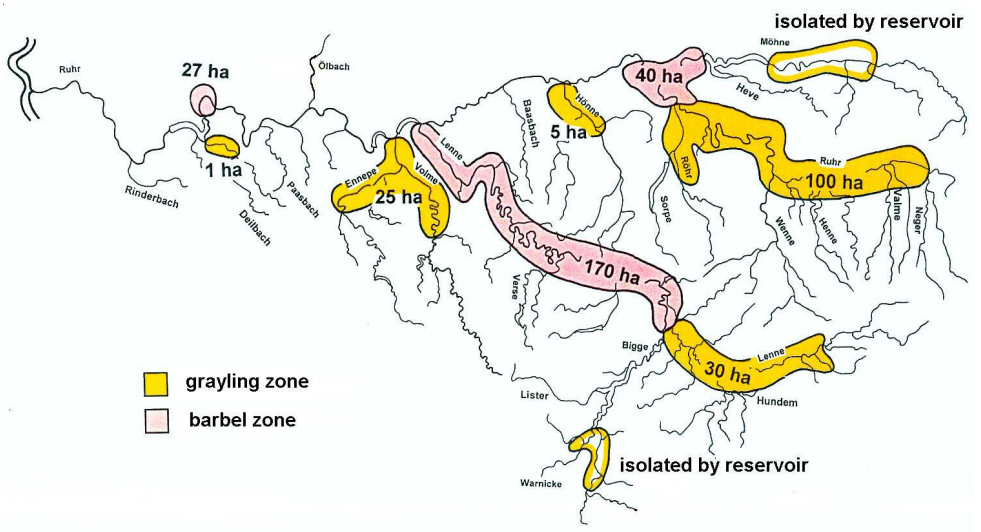

Fig. 3: Potential spawning grounds for gravel-spawning fish species within the Ruhr River Basin

gen concentration in the sediment of 5 mg/l is considered the critical value during the development phase of the spawn [7]. Various investigations undertaken in recent years show that in spite of the water quality improvements, inadequate oxygen conditions still prevail in many river sections within the Ruhr River Basin and other rivers in NRW [5]. Fine organic and inorganic sediments lead to clogging (colmation) in the interstitial system, preventing important exchange processes between the flowing water and the river bed. Furthermore, due to the loss or absence of morphological dynamics caused by bank reinforcements and artificial barriers, there is no sufficient re-arrangement of the river bed during flood events, so that oxygen can not permeate into the interstitial gravel structures.

Special research into the issue of river bed clogging carried out by the Ruhrverband in co-operation with the University of Muenster, clearly showed that it is possible to enhance the ecological conditions in rivers with targeted management measures, in particular, the oxygen balance in potential spawning habitats for migratory fish species [8]. The results of these investigations pointed out that, in principle, there are suitable habitat structures in the Ruhr River system that would allow anadromous fish species such as salmon, lamprey and sea-run trout to reproduce. If seen under the aspect of the desired capability of self-reproduction, it appears that the necessary spawning areas for anadromous salmonide fish are predominantly located in the grayling zones of the upper Ruhr, upper Lenne and their tributaries. The accessibility of both areas is presently still blocked by some 41 weirs in the Ruhr and by some 55 weirs in the Lenne.

4 Estimate of expenditure for fishways and fish passage installations in the Ruhr and Lenne

In order to qualitatively compare the two passage corridors Ruhr and Lenne, the costs required for river continuity restoration were roughly calculated. This implicated the selection of suitable state-of-the-art fishways for every weir along the respective corridor, in line with the general hydrological and biological conditions, such as low-water and flood discharges, fish zone and target species. The relevant cost estimates are based on unit prices for specific standard designs. The computed construction costs for fishways at the currently insurmountable weirs are as follows:

- Ruhr passage corridor (between the mouth of the Ruhr River at Duisburg and the grayling zone in the upper Ruhr River): total € 20.7 million
- Lenne passage corridor (between the mouth of the Ruhr River and the grayling zone in the Lenne River): total € 18.3 million

Since the size of the spawning area which could be rehabilitated at comparable costs is larger in the upper Ruhr, it goes without saying that the Ruhr passage corridor should be given priority.

Due to the multiple water uses of the rivers Ruhr and Lenne described above with 52 respectively 40 hydropower stations, the main problem of any river continuity restoration or nature conservation efforts in the Ruhr River Basin however, is to (re-)establish a safe downstream passage route. The downstream migrating young salmon smolts and adult eels need to be protected from potential turbine entrainment. Full protection for all species along the Ruhr passage corridor - with the need to install screens with 10 mm spacings and appropriate bypasses - would involve costs of no less than approx. € 170 million. Even if structural measures were confined to the protection of a number of target species - encompassing salmonides and eels only - with a correspondingly reduced technical

expenditure (20-mm screens) and specific turbine-management measures - the costs would still be in the range of € 50 million. However, just to consider the high costs involved is not purposeful *a priori* and does not necessarily lead to the desired goal. Even "full protection" does not assure a 100 % survival rate for the fish at the hydropower stations. Consequently, due to the 'chain reaction' generated by the great number of power stations in the rivers Ruhr and Lenne, only ~58 % of the salmon smolts, starting their downstream migration in the grayling zone, would manage to work their way down to the Ruhr River's mouth in Duisburg (in the full protection scenario) and just ~13 % smolts would do so (in the target species scenario). Thus, without drastically reducing the great number of hydropower plants in the water body course, it is practically impossible to restore the river's downstream continuity for diadromous species with a satisfactory result.

Against this background, a pragmatic approach worth considering is a short-term connection and development of suitable spawning grounds close to the Ruhr River's mouth into the Rhine, which are located in the rivers Deilbach, Ennepe and Volme. Unfortunately there still exists a number of weirs with considerable heights which need to be passed in order to reach these spawning grounds. Moreover it is doubtful whether or not the existing spawning ground areas are large enough and suitable from the point of view of quality, for a sustainable fish species reproduction as well as for a successful natural fish diversity development.

To promote the return of migratory fish into the Ruhr River system under these circumstances within a reasonable period of time, an alternative concept was developed for the diadromous target species and the primary Ruhr passage corridor. This concept considered the current and potential future water uses along the Ruhr River. By this, the fish passage is ensured by means of the so-called "trap & truck" technology. Its basic idea is to enhance the survival rate of the returning fish by trapping them in appropriate installations or facilities, drawing them into a tank and transporting them past the chain of river barriers by overland vehicles to a release site below or above. This technology has been implemented and is successfully operated - amongst other things - on the Garonne River (Southern France) and on the Columbia River (USA). The approx. construction costs in the "trap & truck" scenario amount to € 30 million; annual O&M-costs were estimated at € 0,5 million. As the rated overall salmon smolt survival rate in this scenario is 80 %, trap & truck would therefore represent a meaningful contribution to the re-colonisation of diadromous species until the final removal of all up-and downstream obstacles in the migration corridor. Further, such an interim solution would be helpful to enhance the understanding of the spawning areas' suitability and performance and of all other additional measures required to connect and develop these grounds.

5 Results of the master plan and conclusions

According to the WFD, the longitudinal and lateral river continuity is one of the essential environmental objectives to be established for surface water bodies in order to achieve a good ecological status. In view of more than 1,200 barrages within the Ruhr River Basin, the Ruhrverband developed a master plan for possible fish passage restoration. This concept not only dealt with technical issues, such as design and construction of fishways, but also with the demands of the existing as well as type-specific fish fauna in the river basin. The 'catalogue of questions' was complemented by investigations of the river sediment as potential spawning habitat and fish nursery. The study also focussed on the conditions in the hyporheic interstitial, in order to identify appropriate river reaches to support successful fish reproduction.

The study ascertained that there are suitable habitats for diadromous fish species within the rivers and streams of the Ruhr River Basin. As fish migrations are restricted by multiple barriers, fishways should be constructed in a first approach. This is possible by applying the available technology. Potamodromous as well as diadromous fish species would benefit from these projects. However, the overall costs for fishways to assist upstream migration to the two identified primary target areas (in the upper reaches of the Ruhr River and Lenne River) are in the range of approx. € 30 million. Lower specific costs, the size and ecological potential of the areas under review suggest that top-priority should be given to the restoration and development of the target zone in the upper Ruhr.

On the other hand, downstream passage restoration for diadromous species (in particular to connect the two primary target areas) currently does not seem promising, due to the impact of the barriers which increases progressively with the number of weirs in the rivers - even if the necessary techniques were available. It appears, at least for the time being and the foreseeable future, that a re-colonisation of anadromous salmonidae in the two principal target areas should be dispensed with. If, for any reason whatsoever, such a project were to be put into practice, a successful migration of fish in their different life stages could only be secured by the "trap and truck" method. Possible other interim solutions for a successful re-colonisation are seen, for example, firstly in an initiative to connect tributaries to the Ruhr River that are located closer to the River Rhine.

Recent investigations have confirmed that the catadromous eel, which is mainly found in the barbel zone, is a highly endangered species. Effective measures for its protection should be taken without delay. Given the fact that no efficient fish screens exist at medium- or large-scale hydropower plants, the survival rate can obviously only be increased by a "fish-friendly" turbine management.

Additional investigations into the oxygen supply of the hyporheic interstitial affirmed the positive influence of targeted management measures. This indicates that it is possible to enhance the flow dynamics in rivers by specific restoration measures (such as integration of rock 'obstacles' and dead wood and/or removal of bank reinforcements) and to create appropriate spawning conditions for the fish. Such measures will support the formation of fresh gravel banks, rich in oxygen, which are prerequisite for the successful reproduction of all gravel-spawning fish species.

The investigations demonstrated the importance of integral, catchment-wide and cost-effective planning in complex river systems like the Ruhr. Further, they illustrate the inherent problems of projects aimed at river continuity as well as vertical connectivity restoration for the fish fauna in water bodies which are strongly affected by anthropogenic modifications. The results obtained may well be transferred to other river basins with similar conditions and water uses.

In conclusion it is important to point out that the decision whether, or to what extent river continuity is restored, will in the end be based on the outcome of a political and social rather than a professional discussion. The Ruhrverband identified the necessity to illustrate potentialities and measures for achieving a good ecological status as far as fish passage restoration is concerned in an early stage of the WFD implementation process. Based on the results of the master plan, it will help to develop solutions to meet the requirements set up by the WFD in co-operation with all interested stakeholders concerned. This may also mean to influence official water-policy demands in a practical and pragmatic way if necessary, and to search for economical solutions in every single case, as well as to minimise the cost-benefit-ratio for the Ruhr River Basin as a whole.

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