BREAK FREE

Restoring the biodiversity of rivers by removing dams

Dams serve different purposes such as irrigation for agriculture, storage for water supply, flood risk management and the generation of electricity. Hydropower currently represents 60 % of the energetic renewable mix in the USA and 35 % in Europe. Worldwide, over 58,000 large dams have already been built. Large dams are structures over 15 m or above 5 m with a capacity of 3 million cubic meters water. In Europe, "The Guidance on Barrier removal for river restoration", a report from the EU Commission estimates that there is in average a dam or a weir every 1.5 km on European rivers. The main negative impact on biodiversity is the threat to migratory fishes such as salmon, eels or sea lamprey; and all the terrestrial species whose nutrition is dependent on these fishes, such as bears, wolves, birds etc. According to the "Living Planet Report 2020" of WWF, 509 new dams are planned or under construction in legally designated protected areas such as national parks, nature reserves and land inhabited by Indigenous people. 1,249 dams are already located in protected areas. The results of this publication show an average decline of birds, amphibians, mammals, fishes and reptiles of 68% since 1970. Hydropower dams are cited as a leading cause of this decline.

LIVING RIVERS FOUNDATION engages in the protection of free rivers and freshwater life, sustainable management of water resources and the revitalisation of rivers landscapes – in Europe and internationally. Together with our partners, we support efforts to permanently protect all remaining free-flowing rivers and to remove obsolete river barriers: prioritizing high impacting barriers to restore river connectivity.

Migratory fish make up a crucial link in the food chain and play an important ecological role in productive river systems. Furthermore, they provide an important food supply and livelihood for millions of people around the world. Dams are blocking these fish while they need to migrate to reproduce, feed and complete their life cycles. Hence, migratory fish around the world are severely threatened. Ongoing river fragmentation and dam construction are two of the greatest global threats to freshwater biodiversity and ecosystem functioning.

While many dams have been of great benefit for people, in Europe alone, there is an estimated number of 150,000 mainly small dams which are now obsolete. Recent reports from Europe and the USA conclude that the removal of dams is a very effective ecological restoration measure as rivers recover faster than expected after dam removals. Furthermore, it is becoming increasingly clear that dam removal is often a cost-effective measure. For these reasons the World Fish Migration Foundation, WWF, the Rivers Trust, TNC, Wetlands International Rewilding Europe and the European Rivers Network started Dam Removal Europe (www.damremoval.eu) in 2016. Living Rivers Foundation is one of the registered Supporters of Dam Removal Europe. The ambition is to make dam removal a viable option for river management and to restore rivers and it's fish populations. The development of this movement is a major success. Policies have been positively influenced in Lithuania, Finland and Sweden. And as a result of our joint policy lobby the European Union has included specific biodiversity targets to restore 25,000 km of free-flowing rivers by removing dams.

Another crucial development is the fact that an specific private fund was launched this past November 2021 to remove barriers, the European Open River Programme with a value of 42.5 million Euro. This is a special Programme to catalyse dam removal in Europe. The Dam Removal Europe coalition is ready to replicate and scale up dam removal all over Europe, through channelizing funding, stimulate knowledge exchange and sharing best practices and implementing the new European biodiversity goals for free flowing rivers.

European water and nature policies are now getting aligned for this new 'riverlution' to restore the biodiversity of European rivers and to have rivers full of fish again. The ultimate ambition of WFMF is to replicate the experiences from the USA and Europe and create a global dam removal movement.

Herman Wanningen, Pao Fernández Garrido and Elena Alfaya
World Fish Migration Foundation

Migratory fishes and their importance in promoting resilience of freshwater ecosystems, and for human and food security – A focus on Salmon and Eel

Fish constitute one of the major protein sources for humans around the world. 10,000 out of the 25,000 known species of fishes are freshwater fishes.

Migratory fishes that are living subsequently in freshwater and in salty water are called diadromous fishes. We can distinguish three types of migratory diadromous fishes.

"Catadromous" fishes migrate down the rivers to spawn in the sea. Eels are an example of catadromous fishes. In contrast, **"anadromous" fishes** like salmon, sea trout and sea lampreys are migrating up the rivers from the sea to spawn. The third category is called **"amphidromous"**. Unlikely to the two other types of **diadromous fishes**, they migrate for other purposes as breeding and the migration is independent of their age. Gobies are an example of amphidromous fishes. Whether anadromous, catadromous or amphidromous, all migratory diadromous fishes need the river as a habitat to fulfill their life cycle.

Under natural or close to natural conditions migratory fishes, such as salmon, eels and sea lamprey have a high potential of reproduction and regeneration following impairments. Their genetical diversity allows them to adapt fast to dramatic events including volcanic eruptions that might devastate parts of the river streams for some time or to more extreme whether events like those related to climate change. Another important role is that they act as an ecological memory. By acting as energy and nutrient reservoirs, and as gene pool storage between years and ecosystems, migrating fishes link spatial and temporal scales (Kairesalo et al., 1987; Cederholm, 1989). They are also indicators of the past climate changes on a long-term scale.

Not only are migratory fishes keystone species in freshwater ecosystems themselves, but they also improve the resilience of the whole net of freshwater dependent river ecosystems.

Fishes have the ability to mineralize nitrogen and phosphorus through excretion and defecation, making these nutrients available for primary production. Therefore, they have a role in the regulation of food webs dynamics on terrestrial and aquatic levels and nutrients balances. High nutrient input and high primary production are increasing carbon fixation (Tin-Yu Lai et al., 2021).

Fundamental ecosystem services	
Regulating services	**Linking services**
► Regulation of food webs dynamics ► Recycling nutrients ► Regulation of ecosystem resilience ► Redistribution of bottom substrates ► Regulation of carbon fluxes from water to atmosphere ► Maintenance of sediments processes ► Maintenance of genetic, species and ecosystem biodiversity	► Linkage within aquatic ecosystems ► Linkage between aquatic and terrestrial ecosystems ► Transport of nutrients, carbon and minerals ► Transport of energy ► Acting as ecological memory
Demand-derived ecosystem services	
Cultural services	**Information services**
► Production of food ► Aquaculture production ► Production of medicine ► Control of hazardous diseases ► Control of algae and macrophytes ► Reduction of waste ► Supply aesthetic values ► Supply of recreational activities	► Assessment of ecosystem stress ► Assessment of ecosystem resilience ► Revealing evolutionary tracks ► Provision of historical information ► Provision of scientific and educational information

Major fundamental and demand-derived ESS provided by marine and freshwater fish populations

It has also been shown that their active or passive function as transporters and distributors of energy and materials can enhance primary production in nutrient poor environments. The life cycle of anadromous fishes, like salmon, through marine-derived carbon and nutrients contributes to the production of algae, insect larvae, microbial decomposers thus providing favorable conditions for young salmon and other fishes in the river. Marine-derived nutrients and organic matter from anadromous fishes can stimulate biomass production up to 50 kms downstream. The timing of this linking service between ecosystems has to be taken in account. Indeed, these nutrient inputs happening from late autumn to early spring permits to support the nutrient load at a period of the year, when other sources of nutrients are naturally scarce. Catadromous fishes, due to their long-distant migration, are also supporting nutrients, carbon and other substances transport from one part of the world to another.

According to the study on "Ecosystem services generated by fish populations" (Cecilia M. Holmlund et al., 1999), there are two main types of ecosystem services (ESS) provided by marine and freshwater fish populations: fundamental ecosystem services and demand-derived ecosystem services. Fundamental ecosystem services provided by fish are not replaceable by technological innovations. All demand-derived ESS are dependent on natural systems.

The main cultural services provided by migratory fishes are the production of food for humans (oil, protein, etc) and the production of medicines, such as antibiotics. They also promote recreational activities like fishing and have an aesthetic value.

They are at the same time an important source of information for scientists, especially considering the monitoring and the assessment of ecosystem stress. They permit to identify changes in the ecosystem by studying their population, before the changes in the ecosystem itself can be seen. They are "early-warning signals" of anthropogenic stress on natural ecosystem dynamics, or indicators of ecosystem recovery and resilience (Carpenter et al., 1997). Thus, migratory fishes are also a tool to monitor human influence on water quality.

We are currently facing a global biodiversity crises. Some researchers estimate that the extinction rate of freshwater ecosystem related species is twice as high as that of other habitats. River ecosystems worldwide suffer a lot from excessive chemical and nutrient pollution, waste dumping, channelization and river regulation, water abstraction and from cutting of their natural floodplains.

While the complete breakdown and the extinction of most sturgeon populations in Europe is mainly related to overfishing, the fate of fishes adopted to free flowing rivers has been heavily effected by barriers like weirs and dams that are erected in their water courses. It is hard to imagine that rivers like the Rhine and the Elbe had salmon runs far exceeding hundred thousand individuals still in the 1880s even though they were already on the decline by that time. Nowadays, institutions like the international river commissions try to at least reestablish populations of several hundred individuals.

For anadromous species, such as salmon, the free access to the river is essential. They need to reach the headwaters with gravel beds for the female to dispose their eggs after the fertilization by the male subsequently covering it with gravel to protect the embryos from the rapid stream current and provide a vivid habitat for a variety of species. While salmon can jump over smaller obstacles other fishes like sturgeon lack that ability. Dams in the rivers directly lead to a dramatic decline of all migratory fish populations due to the disconnection and fragmentation of the river courses.

Many big dams are not provided with fish ladders. Furthermore, dams and weirs regularly turn currents and streams to reservoirs dramatically changing the original habitat conditions and holding back sediments. Silt and sand are accumulating in the reservoir while erosion downstream the dams increases. At the same time some river stretches fall completely dry and/or are faced with a massively changed hydrological system.

Fish ladders allow catadromous fishes to go upstream the dams to access their spawning grounds. For most dams around the world however, fish ladders are either completely missing or only partially operational.

In a context of climate change, providing the return of migratory fishes in their natural habitats and promoting their life cycle by removing dams is a great tool to secure resilience during ecosystem perturbation and safeguards the future health of natural and social systems (Folke et al., 1996; Dayton, 1998).

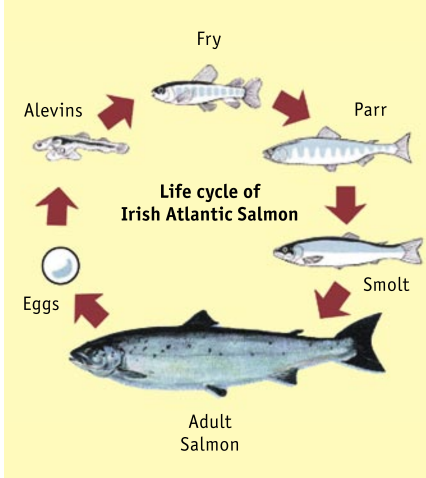
The **Colorado River** (USA and Mexico) is a striking example of what happens when a river is too fragmented. The intensive use of water for agriculture in Arizona, upstream Mexico, eventually led to the drying up of lands in Mexico and the destruction of an entire ecosystem. It is also a showcase of conflicts between users and the need to review what is called the "Law of the River" (1922), as the Colorado management is divided between US and Mexico. The Colorado River can't reach the river mouth anymore and the connectivity between the see and the river is lost, impacting the whole biodiversity of the different ecosystems present in this section. As sweet water and salty water don't mix anymore, the soil of mouth of the river is saline and inhospitable to vegetation.

The case of the Colorado River shows the immediate urge to adopt an integrated management of water resources and develop innovation, as the current water management model has completely failed to take the minimum ecological considerations into account. The Sonoran Institute has developed a pilot project to restore the freshwater ecosystems in the state of Sonora, Mexico. You can discover more about their activities following this link:

- *https://sonoraninstitute.org*

Focus on the Salmon:
Anadromous migratory fish

There is only one specie of Salmon *(Salmo salar)* thas is migrating upstream European rivers. Its feeding habitat is located in the Atlantic Ocean. On the American West Coast six Pacific salmon species can be found *(Oncorhynchus gorbuscha, O. Keta, O. nerka, O. kisutch, O. tschawytscha and O. rhodurus)*. The female salmon disposes its eggs on the ground so that the male salmon can fertilize them. They will be covered with gravels and sand. When they reach the phase of what we call "smolts", they go down the river towards the sea and migrate to the ocean to grow and feed themselves: it is the maturation phase and it takes, depending on the species, from 1 to 5 years. They can travel on super long distances (sometimes over 1,000 kms) and against strong currents. Having spawned they are called "kelts". Kelts usually don't survive due to the use of energy to migrate and spawn. They are also more subject to diseases and predators. Those that survive will effectuate the migration to the ocean again and then go back to spawn in the river. Studies have shown that usually the females spawn exactly at the same area as they did the first time. Scientists explained that salmon use the earth's magnetic field to find their river and then use the smell to find their spawning area. The "smell-memory bank" is built as they are young fishes, before migrating to the ocean.

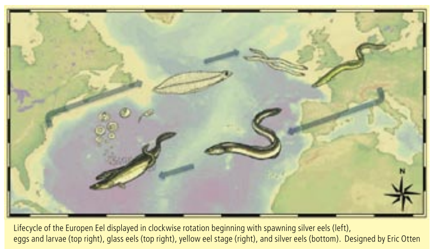


Life cycle of the Irish Atlantic Salmon
(Tom McDermott, Marine Institute, Ireland, 2020).

Focus on the Eel:
Catadromous migratory fish

Eels are a catadromous specie, meaning that their feeding area is located in the river and their spawning area in the sea. More than 800 species are distributed worldwide, and they all belong to an order of fish called "Anguilliform".

They have the ability to migrate far away from their spawning areas: over 1,000 kms. The Sargasso Sea, on the west of North America in the Atlantic Ocean, seems to be the main spawning area for European eels. Then the larvae migrate towards European shores following the Gulf Stream current. During their migration, they transform into juveni-



Life cycle of the European Eel (Eric Otten) les or “glass eels” with a size around 6–7 cm. In average eels spend 5 to 20 years in inland freshwaters to feed themselves and grow. After this phase of maturation, the yellow eel is migrating again, towards the Sargasso Sea in the Caribbean, their spawning habitat. They finally reach their last stage of life becoming adults, or “silver eels”, while migrating. The size of an adult male is around 35–40 cm, when the size of an adult female varies from 40 to 100 cm.

For this specie as well, dams and other obstacles are impairing their survival. Eel ladders are built in some dams, only. Eels are highly vulnerable to hydropower installations during their migration downstream. The high water levels in reservoirs is another limiting factor to their migration through the dams. According to several studies, eels are a great indicator to river-ocean connectivity and can serve as an umbrella and flagship species, making them a comprehensive surrogate for the conservation of freshwater biodiversity. They are widely distributed, higher-order predators that are generally larger than other freshwater organisms and are easily identifiable. In 2016, IUCN (International Union for Conservation of Nature) decided upon the “Promotion of Anguillid eels as flagship species for aquatic conservation”. Over the past 40 years, the number of European eels arriving to Europe dropped by at least 90 %.

This specie is close to extinction and one of the main explanations is the blocking of their pathway for migration, such as dams and weirs. They are also sensitive to climate change, pollution and intense fishery.

This massive extinction led to disturbance on the market of eels. Therefore the EU Commission adopted in 2007 the “Eel Regulation”, whose principal measures are to make easier the migration of eels, limit fisheries, allow 40 % of adult eels to escape from inland waters back into the sea where they spawn, and restock suitable inland waters with young eels.

Sources:

- *“Ecosystem services generated by fish populations”, Cecilia M. Holmlund, Monica Hammer, 1999;*
- *“The Role of Food Web Interactions in Multispecies Fisheries Management: Bio-economic Analysis of Salmon, Herring and Grey Seal in the Northern Baltic Sea”, Tin-Yu Lai et al., 2021;*
- *Steckbrief “Revitalisierung Kleiner Fliessgewässer in Elbe-Einzugsgebiet nordwestlich von Hamburg”, Ludwig Tent, Michael Bender et al., 2019;*
- *https://www.marine.ie/Home/site-area/areas-activity/fisheries-ecosystems/salmon-life-cycle*
- *https://sonoraninstitute.org*

Hydropower – a green, cheap and clean source of energy production? Examples from the Mekong River (South East Asia) and Italy

Hydropower has been used for centuries to directly power machines and mills. Nowadays it is mainly producing electricity using the gravitational potential or kinetic energy of a water source.

There are several types of hydropower, such as run-of-river, storage, pumped storage and offshore hydropower. For most big Hydropower plants dams are installed into the main river course turning part of the rivers into artificial lakes or whole chains of subsequent lakes. It is what we will focus on in this publication.

Hydropower is still widely viewed as a green and clean energy, with low or no emission of greenhouse gases. In reality it is not so easy and the environmental impacts of dams are usually underestimated and would include impacts on biodiversity (plants and migratory fishes), as well as on the hydromorphology of the river, the conflict of water use, the risk of breach, the displacement of populations living upstream and sometimes even the risk of droughts and floods for populations downstream or living from the natural resources of the river. In some cases, high greenhouse gas emissions have been observed.

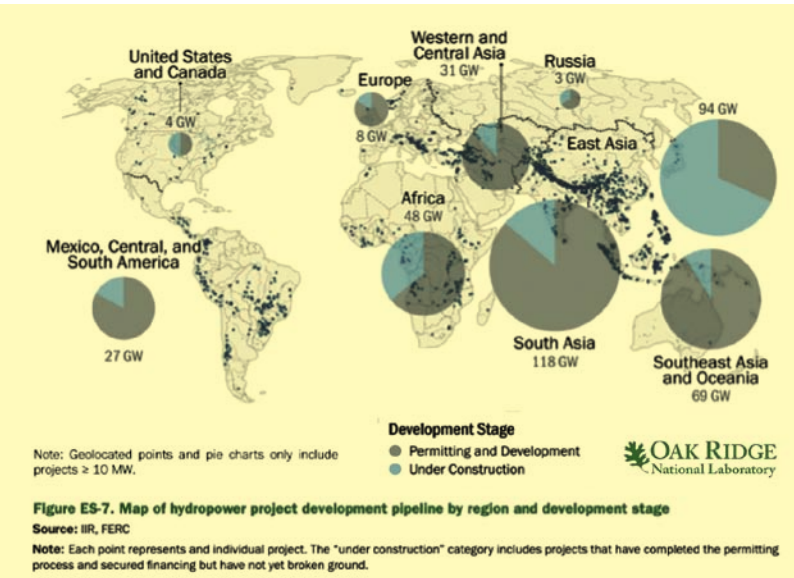


Figure ES-7. Map of hydropower project development pipeline by region and development stage
Source: IIR, FERC
Note: Each point represents and individual project. The "under construction" category includes projects that have completed the permitting process and secured financing but have not yet broken ground.

Map of hydropower Project development pipeline by region and development stage (IIR, FERC, 2019).

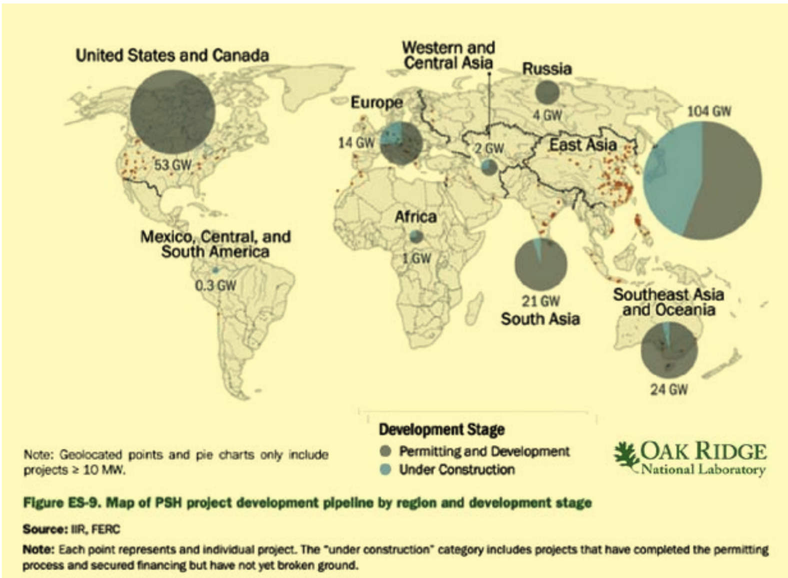
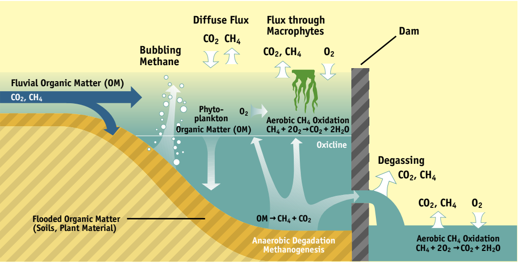


Figure ES-9. Map of PSH project development pipeline by region and development stage
Source: IIR, FERC
Note: Each point represents and individual project. The "under construction" category includes projects that have completed the permitting process and secured financing but have not yet broken ground.

Map of PSH project development pipeline by region and development stage (IIR, FERC, 2019).



CO_2 and CH_4 pathways in a freshwater reservoir with an anoxic polimnion (adapted from Guérin, 2006)

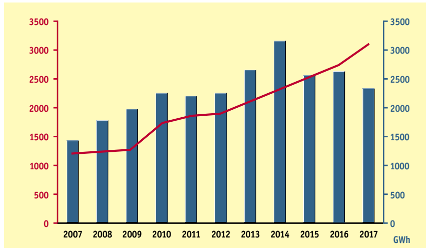
In his article "Sustainable image problems: How the Hydropower Industry tries to present itself greener as it is" Dr. Thilo F. Papacek, Project Manager from the German NGO CounterCurrent, states that the new published Hydropower Sustainable Standard from IHA (International Hydropower Association), instruments to measure impact of dams on populations and ecosystems, doesn't really aim to reform the industry but more to give it a green coat.

Following the industry proposal, installed hydropower capacity worldwide should be increased by 850 GW to reach 2,500 GW, to limit global warming to 1.5 degrees as planned in the Paris Climate Agreement. This would mean to nearly double the installed hydropower capacity worldwide, damming the last free-flowing rivers and thus to destroy valuable ecosystems of rivers and connected floodplains and to displace millions of people. Such an expansion of hydropower industry asks again the more than ever current question of human rights, regarding access to water and land grabbing; but also the use of public funds for such projects.

Moreover, climate crises, and especially energy shortages caused by severe droughts, in some regions (for instance in Chile or Brazil) tend to limit the possible share of hydropower in the energy mix. At the same time more likely cases of extreme rainfall events causing floods might put higher risks to the infrastructures and the population (Malawi). As Dr. F. Papacek says "the most sustainable hydropower plant is still the one that is not built."

The phenomenon described earlier also occurs in Italy. Although the number of plants increases, the production of electricity diminishes (see years 2015 – 2017).

Italy is an example of over-exploitation of natural waterways by hydropower, financed by public aids. Since 2009, more than 2000 plants have been authorized whenever the hydroelectric production stagnated. Associations are raising against financial support given from the State and irregular renewal of concessions on large dams: Italian Government State Aids are among the highest in intensity in Europe, according to the National Coordination for the Protection of Rivers, Free Rivers Italy. Again, the costs of production are shared by the public, when the profits are privatized and stay in the hands of the industry. Even the EU Commission has contacted the Italian Authorities to warn them of the over-exploitation, since the potential of hydropower in Italy has already been reached 95%. The lack of transparency on projects under scrutiny for authorization makes the work of EU, CSO and NGO even harder but there is an estimation of 500 new plants waiting for the State Aids.



Comparison between the number of plants and production in the years 2007–2017 after the introduction of the incentive, in Italy.
(GSE: https://www.gse.it/en)

David H. Blake: "Fluvicide on the Mekong River"
(This is a summary of a presentation given at the European Rivers Summit, Lisbon, on 18 November, 2021)

In 2001, American ichthyologist Tyson Roberts published a paper in the Natural History Bulletin of the Siam Society titled "Killing the Mekong: China's Fluvicidal Hydropower-cum-Navigation Development Scheme". In the paper, Roberts argued that if China proceeded with building a series of large dams on the Upper Mekong, then inevitably there would be a catastrophic decline in the wider Mekong river system's ecological health, as far downstream as the Delta in Vietnam.

The regulation of its flow regime and sequestration of sediments and nutrients in the upstream reservoirs would lead to a "massive loss of biodiversity", including many migratory species of fish that form the basis of incredibly productive freshwater fisheries, that would impact millions of people dependent on this fishery. He noted that the ecological impacts from the dams would not act individually, but cumulatively, negatively affecting entire societies.

As far as I am aware, Roberts was the first person to use the term "fluvicide", which came back into usage through a synonym in 2021 in a live documentary titled "Rivercide" made by environmental journalist George Monbiot, documenting the recent ecological decline of the River Wye along the border of Wales and England, in part due to a rapid expansion in intensive poultry farming. Both fluvicide and rivercide can be considered sub-categories of "ecocide", defined by Stop Ecocide International as, "unlawful or wanton acts committed with knowledge that there is a substantial likelihood of severe and either widespread or long-term damage to the environment being caused by those acts."

What has actually transpired in the Mekong Basin over the last two decades following Roberts' dire predictions, and to what extent have they been borne out in reality? The first observation to note is that the scale and pace of dam development across the region, but especially in Laos, has been far greater than anyone could have imagined in 2001. The dam building boom got underway in 2005, following a release of funding by the World Bank to build the $1.5 billion Nam Theun 2 dam hydropower project in central Laos, precipitating a flood of cheap credit into the region for large hydropower projects. Yes, electricity has been produced and transmitted from remote areas to urban centres and industrial estates, but the power is neither green nor clean, as proponents claim, and the socio-environmental costs have been vastly underestimated.

Since 2005 hundreds of hydropower and irrigation dams have been built across the region, with nearly 140 being completed between 2010–14 alone. Laos has been the epicentre of the boom, and styled itself as "the Battery of Southeast Asia", with electricity produced wheeled to neighbouring states, principally Thailand. Much of the finance has been sourced from East and Southeast Asian banks, both private and state funded, with China being the most influential country, followed by Thailand

and Vietnam. Western companies have benefited from consultancy and engineering contracts in the construction frenzy. China has built a cascade of 11 dams on the upper Mekong river and is still planning on constructing more, while Laos has built two mainstream dams on the Mekong completed in the last two years (Xayaburi and Don Sahong), with several more underway and has plans to build scores more across its portion of the basin.

Over the same period, there has been an accelerating decline in the Mekong's vital health signs, with significant changes in the river's hydrological regime and sediment-nutrient load being the most stark. In essence, the onset of the river's annual flood has been delayed and reduced in height and duration, while the dry season flows have increased due to hydropower releases, an effect that becomes more noticeable the further upstream towards China one travels. Almost daily, stories in local and international media sources report that fish catches are plummeting on the Mekong and its major tributaries, including the Tonle Sap lake and river in Cambodia, formerly the most productive fishery in the entire system. People are struggling to earn a living and feed their families, with no other cheap sources of animal protein available. Aquaculture is not an option for most resource poor households.

In recent years, as anticipated, the Mekong Delta has experienced significantly reduced floods in the flood season, with the water peak arriving a month or two later than normal. That has led to rice fields not receiving a covering of silt and nutrients, while fish catches have plummeted by a reported 90 %. Similarly, rates of bank erosion have accelerated due to the reduced levels of silt accretion, exacerbated by other factors such as extensive sand dredging operations. Upstream in the reaches bordering Laos and Thiland, locals have noted a novel phenomenonin the dry season as the normally turbid brown Mekong has turned cler or appeared "blue". Meanwhile, the delta coastline is crumbling into the sea, as the river's sediment deposition is not sufficient to protect it from ever-rising seas and worsening storms. Whole towns and villages are in danger of being swamped as the densely populated Delta collapses over coming decades. Credible research suggests that much of the Delta could be lost by 2100, as much of it lies less than a metre above sea level.

The Mekong can no longer be considered "mighty". It is in the midst of a man-made disaster that is unfolding rapidly, with the people most seriously affected having the least say in the development process, despite past attempts by some Western development organizations to engender more integrated and democratic processes in water resources management in the region. The river basin organization charged with the management of the Mekong River basin has proven a resounding failure in protecting the river's resources, despite millions of dollars/euros sunk into it over the last 25 years, including significant sums from Germany promoting a "green growth" agenda.

The Mekong River Commission has little to show for its efforts, beyond piles of reports and plans (most of which are ignored by the riparian nation governments) to "sustainably" manage the river's resources. The dams keep on being built and the river's ecological condition continues to slide, despite endless rhetoric by actors. European policy makers and development donors may need to entirely rethink their strategy for the region, including the option of withholding or withdrawing funds from the states, which are all swinging towards deeper authoritarianism.

With reference to dam building on sensitive tropical rivers, Indian author Arundhati Roy, argued that, "To intervene in such a massive way in such a complex process - it's like putting a jackboot into a spider's web." In the case of the Mekong, hundreds of jackboots have stamped on hundreds of spider's webs, and unsurprisingly the river is now in a state of ecological crisis.

David J.H. Blake
29 December 2021 – Tavira, Portugal

Xayaburi Dam on the Mekong River in Laos in 2017.
(Planet Labs Inc/Handout via Reuters)

Xayaburi Dam on the Mekong River in Laos in 2019.
(The Laotian Times)

A new study "Evident but context-dependent mortality in fish passing hydroelectric turbines" (Radinger et al., 2021) from the IGB Berlin has shown that fish mortality varies among fish orders and lengths and turbines' types (Kaplan, Francis, VLH, Archimedes' crew, cross-flow and water wheels). The study is a review of the results of 91 studies, conducted on more than 275,000 fishes, from 75 species, 27 families and 15 orders. In average between 17,5 % and 26,7 % of fish were lethally injured or killed. The study has shown that the highest rate of mortality for a 25 cm long fish is caused by the cross-flow turbines. In general water wheels show the lowest rate of mortality or injuries conducting to delayed mortality. An average mortality of 20 % will unquestionably affect fish stock and especially migratory fish, such as salmon and eel. Cross-flow turbines are mainly used in mini and micro hydropower units of less than 2,000 kW and with heads less than 200 m.

Sources:

- *T. R. Roberts, "Killing the Mekong: China's Fluvicidal Hydropower-Cum-Navigation Development Scheme", Nat. Hist. Bull. Siam Soc. 49:143–159, 2001;*
- *Dr. Thilo F. Papacek "Sustainable image problems: How the Hydropower Industry tries to present itself greener as it is", 2021;*
- *David J. H. Blake "Mekong Fluvicide", 2021;*
- *Mekong River Commission:* *https://www.mrcmekong.org*
- *Coordinamento Nazionale Tutela Fiumi Free Rivers Italia, "Italy Hydropower", 2021;*
- *Radinger et al., (IGB, Berlin), "Evident but context-dependent mortality of fish passing hydroelectric turbines", 2021;*
- *Boyé et de Vivo, (Institut Veolia), "The social acceptability of dams", 2016*

USA: History of dam removal in North America

In the US, the technology of hydropower has been used since the late 1800's. An engineer named James Francis developed the Francis Turbine in 1849. This type of turbine is the most widely used today. In 1882, the world's first electric hydropower plant began its operations in Appleton, Wisconsin on the Fox River. In 1902 the Bureau of Reclamation, currently the 2nd largest producer of hydropower of the US, was established. In 1907 hydropower already accounted for 15 % of the US electrical power generation. Since then, it has played a preponderant role, especially in the 2nd World War, by producing electricity for building ships, planes and other war related materials. Within 60 years the hydropower capacity in the USA has tripled reaching a cumulative capacity of 600 GW in 1980. It was not before 1968 under the mandate of President Richard Nixon that the first environmental regulations were conducted, including the National Environmental Policy Act, the Wild and Scenic Rivers Act and the Fish and Wildlife Coordination Act.

In 2020 there were more than 91,000 dams in the USA, including approximately 10 % large dams, impounding more than 970,000 kms of river, 17 % of rivers in the nation. According to the American Society of Civil Engineers, 70 % of the dams will be more than a half century old by 2025. The ageing of the dams increases the risk of failing. Thus it has to be decided which ones should be renovated and which ones should be dismantled.

The Elwha River dam removal: the largest dam removal in US history so far

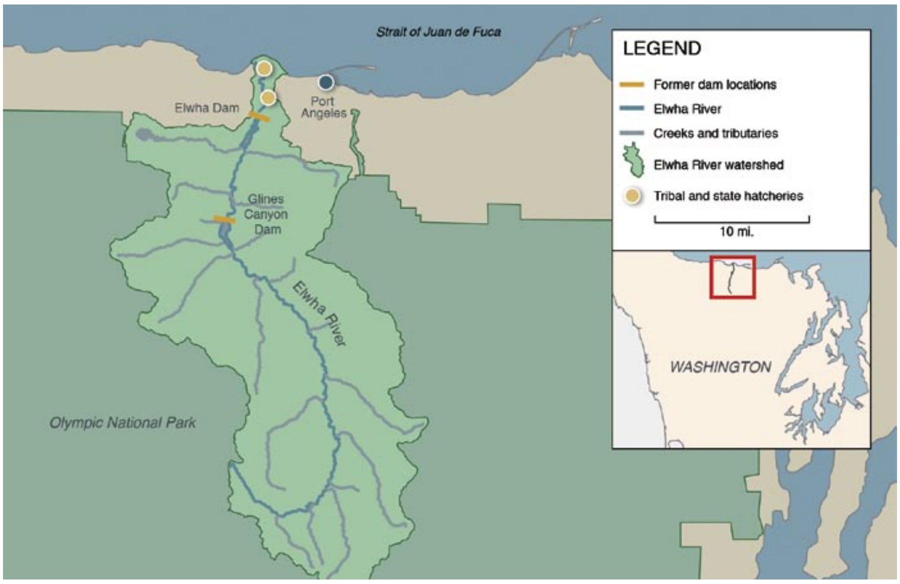
The Elwha River is located on the Olympic Peninsula in the State of Washington, in the North-West of the USA. Two dams were built there: the Elwha dam (33 m height in 1913) and the Glines Canyon dam (64 m height in 1927) impairing the free flow of 133 kms of the Elwha River. The Elwha dam itself was located 8 kms upstream from the river's confluence to the Strait of Juan de Fuca in the Pacific Ocean. According to some sources the dam construction was illegal already at the time of their construction. As for a lot of old built dams, no fish ladders were present. Studies have shown that in the early 1900's, the number of migratory fishes, such as salmon and trout, returning each year plummeted from 400,000 to just 3,000 after the dam constructions. This deprived the local native tribes whose cultural identity has strongly been connected with salmon from their guaranteed fishing rights.

In 1978 the Elwha Dam failed to pass safety inspections, meaning that the tribes living downstream were at risk of catastrophic flood. The Klallam tribe together with conversation groups needed a decade of technical and economical studies to push forward the idea of a dam removal that was so far unprecedented in its scale. In 1992 the Congress passed the Elwha River Ecosystem and Fisheries Restoration Act, authorizing the removal of both dams to restore the altered ecosystem. The dam removal started in September 2011 and was completed in 2014. Still to this day the Elwha River Restoration Project is the largest dam removal in the US history. The cost of this project reached 185 million dollars. It has provided a rare opportunity for scientists to learn the effect of a large-scale dam removal, especially on migratory fishes, such as salmons, on the nutrient cycle provided by these species, and on the ecosystem in general, on the hydromorphology of the river and transport of sediments, etc.

Even after 100 years of inability to reach most of their spawning grounds and dying areas, salmon of all species (in the natural state of the river, there are 5 runs of salmon) and trout had been returning to the river after only 1 year. A monitoring documented that after 3 years, the populations of some of the migratory fishes are showing a great rate of return. But the best return of fishes should occur within the next 3 decades. Their return impacts significantly the restoration of larger terrestrial and aquatic food webs. Thus, the populations of terrestrial fauna, such as bears, cougars, bobcats, mink, otter, birds, and insects, and the growth-back of riparian fauna, as well as that of the deeper forests, have shown significant development. Native plants are reclaiming riverbanks and silt and sand are moving downstream to rebuild the beach at the river's mouth.

By restoring the lifecycle of salmon and especially their role in the nutrient cycle from the sea to the river (marine-derived nutrients, natural fertilizers), the restoration of the whole ecosystem and the biodiversity in general was promoted. A Study published in Ecography in 2015 showed that the life of a very specific specie of riparian bird, called American dippers (*Cinclus mexicanus*), was drastically improved by the salmon's return. The positive effect on human populations, and especially on autochthones and tribes, and their activities is as consequent as it is for other species.

In May 2011, the Lower Elwha Klallam Tribe Hatchery was established in order to help maintain existing Elwha River fish stock during the dam removal. The main issue of this, as pointed out by ecologists and scientists, is that these hatchery fishes are far from the native ones on a genetical point of view. Their reproduction with the native salmon population might impair the genome and genetical diversity, and therefore the adaptation potential of the native fishes. As for every dam removal, the management of the accumulated sediments in the reservoir



Elwha River Watershed (National Park Washington) is one of the most important technical issues to be taken in account in such process. 30 million tons of sediment were trapped behind the dams. One of the challenges for the scientists was to predict the impact of their release on the coastal environment and on the ecosystem in general. Releasing the sediments could potentially damage spawning grounds, roots and stems of macrophytes through abrasion. Algae and insects are scoured as sediments move and are not able to attach to substrate covered with silt and sand, the food quality is diminishing, etc. As short-term effects, the turbidity and the supersaturation on dissolved gases should also be considered. But the gradual removal of the dam mitigated these effects. Surprisingly, most of the sediments reached the coastline within 2 weeks and caused no ecological wasteland at the river mouth. Divers in 15 different spots of the mouth have seen a quick colonization of the new sandy terrain by different species, such as shrimp or forage fish.

In the case of the Elwha dam removal, like in plenty of other cases, the cost of removing two dams and restoring the river, as well as the lost power generation, were outweighed by the benefits to the Lower Elwha Klallam Tribe, nearby communities, and American public. According to the study "Dam Removal: case studies on the fiscal, economic, social and environmental benefits of Dam Removal", (Megan Lawson et al., 2016), the primary economical benefits on recreational and commercial fisheries is expected to reach around 5.3 million dollars, the dam removal and river restoration processes create 760 new jobs and generate 33 million dollars in personal income, and a win of 43.8 million dollars through tourism.

Sources:

- *"Dam Removal: Case studies on the Fiscal, Economic, Social and Environmental benefits of Dam Removal", Megan Lawson, 2016;*
- *"Restoring the biodiversity of rivers by removing dams", Herman Wanningen, Pao Fernández Garrido and Elena Alfaya (World Fish Migration Foundation), 2021;*
- *Movie "Damnation", Patagonia, 2013;*
- *Movie "Return of the River" and other documentaries*

Finland: A successful story of dam removal – general method for dam removal

Finland has quite a special story with hydropower and water governance. Indeed, after the 2nd World War the idea of using all available water for hydropower to support economic growth has been predominant in Finland's water policy and law until the end of the 20th century. In Finland recreational activities linked to fishery are widespread. Dams are considered to be part of a cultural heritage and to have a specific aesthetic value.

However, most dams are currently in a bad state and need to be either refurbished or demolished. Moreover, a considerable number of these ageing hydropower, waterpower and irrigation dams are not fulfilling their original purposes, anymore.

The obsolete dams continued to have serious impacts on freshwater ecosystems, like the disconnection of migratory fishes' pathways and alteration of their habitats, changed physico-chemical conditions (pH, dissolved O_2 and O_2 levels) leading to higher risks of eutrophication, increased temperatures in the reservoirs and to an increased release of greenhouse gases (CO_2, CH_4).

In this context, it occurred that the ecological benefits of dam removal and of flow restoration of the rivers could exceed the loss of cultural aspects.

The first river's continuity restoration efforts in Finland had only begun in the 1980's. In 1995 the SYKE (Finnish Environment

An aerial photograph taken from southwest. In the centre is the dam and next to it on the left side is Vernissa. (The removal of a culture-historical Tikkurila dam for improved resilience of urban nature, Tiia Valtonen, 2017)

Institute) was established to serve as the National River Restoration Centre.

The Finnish Watercourse Restoration Strategy of 2013 puts a framework to related projects. It informs on restoration practices to support citizens and communities in the management of watercourses, provides a cooperation platform for the different stakeholders and promotes good cases and practices through the collection of data and information.

The cultural benefits of dams a well as the ecosystem services of free-flowing rivers affect a variety of users such as scientists, NGOs, cities, business and civil society who need to be involved in public consultations of dam removal projects to raise attention and promote a better understanding of the issues linked to dams and fragmentation of rivers thus increasing the acceptability of the project.

Finland has various successful stories in removing dams. Following is one of them: River Keravanjoki in the center of Vantaa with its Tikkurila Dam. The River Keravanjoki is one of the most important tributaries of the River Vantaanjoki (101 km long, 111 m drop). Due to the surrounding areas of agriculture and human habitation this river is affected by a high level of pollution by nitrogen and phosphorous that is subsequently transported to the Gulf of Finland.

The Tikkurila Dam was 4.5 Meters high, 3 Meters wide and 47 Meters long. It was first built in 1912. The first fish ladders were set up only in 1994, when a restoration was undertaken. In this case, the fish ladder showed several issues as the inability for the fishes to use it, their rapid blockage and represents a danger for people as it is widely opened. The latest original function of this dam was to provide waterpower for linseed oil production but this purpose is not relevant anymore, as the factory closed in 1960.

The dam was in a poor condition and considering the pressure on the ecosystem, the project of the removal was implemented by the city of Vantaa and Ramboll Finland in 2014. The dam removal itself was conducted in 2019. The estimated cost of the dam removal and various works aside were 800,000 Euros.

The project aimed to create a naturally oriented water cycle contributing to the amenity of the city, associating water management and green infrastructure. This was a part of the Green Infrastructure Policy in the framework of EU's policy.

The integration of the various stakeholders has been an important part of the project, due to cultural heritage aspects. The project team was divided in 3 groups:

- *the Steering Group, responsible of the gathering of information and the planning process and composed of staff members and experts from Vantaa City,*
- *the Design Group, which carried out many surveys and headed by staff from Ramboll Oy (engineering consultancy company),*
- *the Technical Board, responsible for directing and monitoring production of services in the city and enhancing the residents' perspective, composed of experts from Vantaa City and other stakeholders.*

For this dam removal, the general method for dam removal decisions of the Heinz Centre ("Dam Removal, Science and Decision Making", 2002) has been used.

From 2014 to 2016: The first three steps were implemented

Several options for the removal were considered. Option 0+ was the refurbishment of the fish ladder (with minimum work and cost) and option 3 was the complete removal of the dam and fish ladders, with additional technical adaptations like fish nursery and habitat areas creation (maximum work and cost). The third alternative had been chosen. In 2016 numerous surveys were conducted on the different compartments (legal, physical, biological, economic and social).

End of 2016: Step 4: Decision Making

The Technical Board accepted the General Plan. In 2017, the Steering Group applied for the Water Permit (mandatory in Finland, for all activities affecting constructions in waters or the water supply). It was granted in 2018. The detailed planning was completed in spring 2019.

3rd June 2019: Step 5: Dam Removal

The central section of the dam was removed, accompanied by the cheering of the population.

Step 6: Data collection, assessment and monitoring

Monitoring of bioindicators, such as mussels, dependent on salmonid populations took place on this area. According to scientists, the monitoring showed impacts on a short-term scale due to the increased release of sediments that affected the water quality. Erosion and change in hydromorphological characteristics due to the change of flow might affect human activities and some species. But considering the long-term scale, there is a diminution of alien species, a decrease of the risk of eutrophication by blue algae and cyanobacteria, the return of recreational activities (fishery) and tourism, riparian vegetation recruitment, restoration of terrestrial and aquatic food webs and the promotion of the overall biodiversity.

A more recent project, so far the largest dam removal in Finland, is taking place on the **Hiitolanjoki River** to restore the rapids of three tributaries of the river by 2024. This will result in free upstream movement to extensive headwaters for the Ladoga salmon and trout, as well as in the additional formation of new breeding sites. Discover more:

- *https://hiitolanjoki.fi*

Sources:

- *"The removal of a culture-historical dam for improved resilience of urban nature", Tiia Valtonen, 2017;*
- *EU Guidance on barrier removal for river restoration, 2021;*
- *"Bringing back ecological flows: migratory fish, hydropower and legal maladaptivity in the governance of Finnish rivers", Soininen et al., 2018;*
- *WWF Finland, Dr. Sampsa Vilhunen*

***The AMBER Project (Adaptative Management of Barriers in European River)** aims to deliver innovative solutions to river and habitats fragmentation in Europe by developing efficient methods of restoring stream connectivity through adaptative barrier management, as well as evaluating the different restoration actions. This might help the stakeholders to decide which barrier are obsolete and must be prioritized (first eDNA application for river restoration), help developing a holistic framework for guiding the restoration of local river ecosystems and provide opportunities for real time monitoring using citizen science.*

*The process is based on the integration of program design, management and monitoring to systematically test assumptions about barrier mitigation, adapt and learn. This project was funded by the European Union's Horizon 2020 research and innovation program. The **AMBER Atlas** is available following this link:*

- *https://amber.international/european-barrier-atlas/*

Step 1: Define goals and objectives

For keeping dam:	For removing dam:
Water supply Irrigation Flood control Hydroelectric power Navigation Flat-water recreation Waster disposal	Safety & security considerations Legal & liability concerns Recreation Site restoration Ecosystem restoration Water quality

Step 2: Identify major issues of concern

Safety and Security	Environmental	Legal and Administrative
Social	Economic	Management

Step 3: Collect and assess data

Legal (Chapter 2)	Physical (Chapter 4)	Biological (Chapter 5)	Economic (Chapter 6)	Social (Chapter 7)

Step 4: Decision making → **Leave in place**

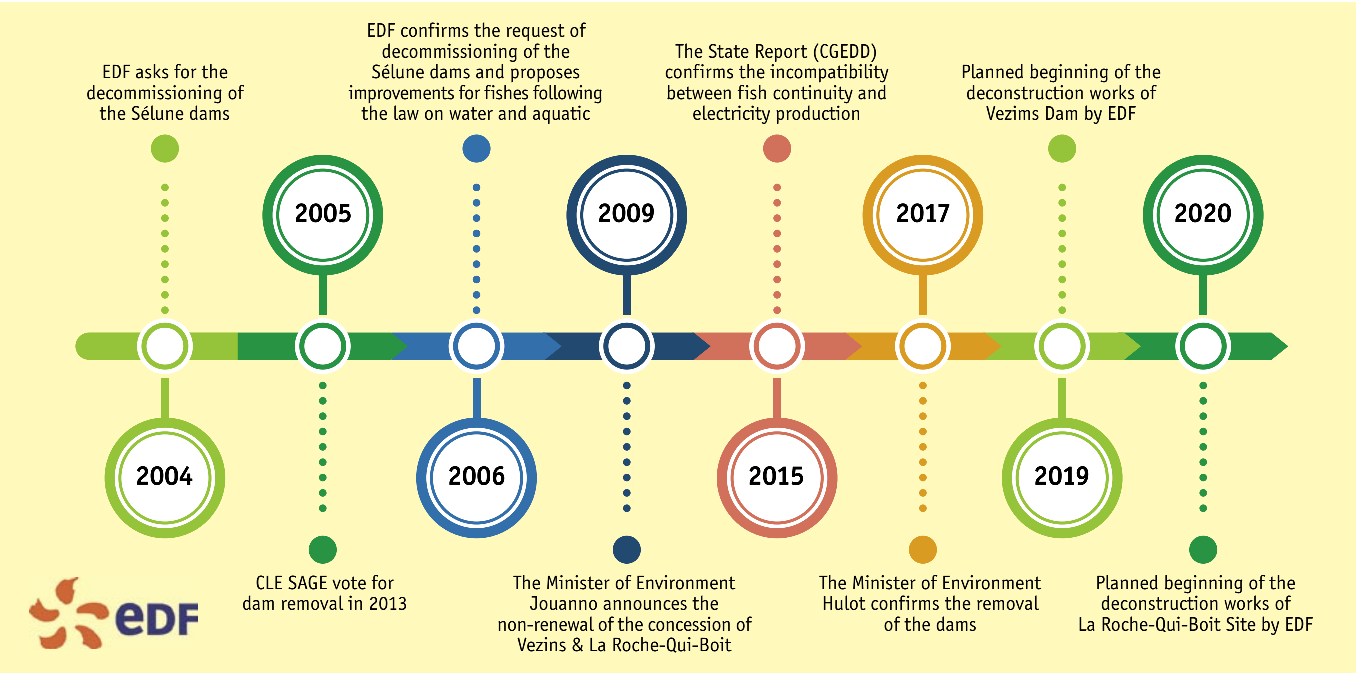
↓ **Remove**

Step 5: Dam removal

Step 6: Data collection, assessment and monitoring

General Method of dam removal decisions (Heinz Centre, 2002).

Dam Removal in France – The Sélune River Project



Timeline of the project of dam removal in the Sélune Valley (2004–2020)

The Sélune River is located in Normandie, France*. In the early 20th century, the river's continuity has been greatly impacted by the construction of two hydroelectric dams: the **La Roche-qui-Boît (LRQB)** dam located downstream (15 m high, 125 m wide, 1920) and the **Vezins Dam** located upstream (36 m high, 278 m wide, 1932). These two dams combined were producing about 27 GWh per year, providing electricity for 15,000 inhabitants. Significant modifications of the hydrological regime (from lotic to lentic in the reservoirs), of water quality and temperature and of biological and biochemical flux have been observed. No fish ladder could be setup on these dams. In 2009, when the concession for the Vezins and LRQB hydroelectric dams was not renewed, the French Ministry of the Environment announced that the dams should be removed in 2012.

The Sélune River Project is seen as an exemplary project in the EU, with the removal of two large-scale dams and has been a long process, which began in 2004. This project is monitored by the "Sélune Scientific Program" which began in 2012 and should run until 2027. In 2019, the scientific program has been extended with an observatory dedicated to the monitoring of the dam removal effects, from the gathering to the publication of data. The goal of the Sélune River Project was to restore ecological continuities between the terrestrial and marine habitats connected by the river basin. The project should allow the return of 90 kms of free-flowing river, and thus the return of the fish continuity and the development of the riparian vegetation. This decision came about as a result of the EU Water Framework Directive (WFD) and the French Grenelle Environment Forum (2009).

In 2014, the first phase of the draining of the Vezins' reservoir was engaged, accompanied by the 1st exposure of the sediments. Due to a decision to the Minister of the Environment (S. Royal) the process was stopped for 3 years until 2017. A new impact study was then run. Between September 2020 and September 2021, the decommissioning of the dam was carried out, for a planned budget of 5 million Euros.

The Vezins Dam

The dam removal of Vezins was decided for several reasons related to the WFD, the low energy production, the inability to adapt the dam and the risk of failure, putting at risk the surrounding population. This project is multidisciplinary and includes research teams in humanities and social sciences (HSS), hydrologists, geomorphologists and biologists in different teams (biocenosis studies, riverine studies, etc.).

According to HSS scientists, the Sélune River Project faced several problems, especially with a big mistrust from the population living in the village of Vezins, despite the several public consultations (2006, 2017), available on *https://selune.hypotheses.org*.

"Les Amis du barrage", an association which promoted leisure activities around the lakes became a figure of this local opposition from 2007.

Alban Thomas highlights the fact that some inhabitants misunderstand the concept of a natural area, by considering the reservoirs lakes as natural and not as artificial. Indeed, a lot of recreational activities, such a fishery and sport activities were provided by the reservoir lake. Alban Thomas also mentions that due to the interruption of the Sélune River Project from 2014 until 2017 (by decision of the Minister of Ecology), the associated land-use planning project had been stopped as well and did not really restart since then, escalating further the conflictual situation with the citizens.

Scale of studies vary from landscape to chemical elements. Before the demolition of the dams, scientists observed the presence of an alien specie of fish called "catfish", certainly introduced for recreational fishery. This fish is a huge predator to other species such as salmon and represented 50 % of the biomass when the emptying of the reservoir occurred. Bloom of algae and cyanobacteria, causing eutrophication, were also common in the reservoirs.

Former site of the Vezin's dam, downstream the reservoir, demolished in 2021.

Former reservoir of the Vezins' dam with the geotubes used for the sediments (orange points) and the riparian vegetation covering the riverbanks.

Locally, some sediments were contaminated with lead, and required a specific treatment. In order to avoid pollution, the sediments were packed in concrete and covered with uncontaminated sediments, to create new side banks. For the deepest sediments, a new technology called "geotubes" was used, to make them dry and then place them on the side banks to permit the further colonization by riparian vegetation.

Unfortunately, no monitoring of the exchange between groundwater and the reservoirs was run before the demolition. Since 2019, a project called "LEARN" is studying these exchanges but no results are yet available. No study on air condition, and the release of greenhouse gases like CH_4 or CO_2 was run before the demolition of the dam.

The Sélune Observatory will monitor the impact of the dams' removals following two aspects: the riverine dynamics (water, chemical and sediments flows) and the monitoring of the biocenoses (biological flows).

The removal of the dam in LRQB was planned between November 2021 and spring 2023, but was pushed back to spring 2022. The activity of the dam of LRQB is already on break. EDF (Electricité de France), the manager of the site has stopped producing electricity in the winter of 2021 and has kept the water level low to prevent the sediments' deposition. The emptying should be completed by May 2022 and followed by the removal.

You can find the entire interview of Alban Thomas, Responsible of the Information System of the Sélune Project, on our website:

- *https://www.living-rivers.eu/en/articles-presentations*

More information on the public consultation processes and integration of the stakeholders can be found at:

- *https://selune.hypotheses.org*

More information on the Ecological restoration of the Sélune River and scientific studies can be found at:

- *https://programme-selune.com/en/*

A Summary of the International Symposium, held in 2019, on "Renaissance of the Sélune valley, erase, restore and enhance", published by the French Biodiversity Agency, can be found here (in French):

- *https://professionnels.ofb.fr/fr/doc-rencontres-synthese/quand-rivieres-reprennent-leur-cours-notes-leffacement-barrages-seuils*

Other sources:

- *"Large dam removal and early spontaneous riparian vegetation recruitment on alluvium in a former reservoir: Lessons learned from the pre-removal phase of the Sélune River Project (France)", Ravot et al., 2019*

La Roche-qui-Boît dam (EDF Property), with an opening on the right side and the factory on the left side.

Zoom on the opening.

Climate change and the water cycle have close and often unrecognized links. Tackling climate change also asks for the restoration of biodiversity and freshwater ecosystems in order to increase the resilience and to meet the EU Biodiversity Strategy 2030 target and the objectives of the Water Framework Directive, respectively the restoration of 25,000 kms of free-flowing rivers and achieving a good ecological status for European waters.

The functions supported by the water cycle in human activities, in agriculture or in cities are vital. Restoring biodiversity permits to relocate water resources. The EU provides tools and funds to help organisations, scientists and civil societies for the prioritization and the restoration of ecosystems. The **AMBER Project** funded by Horizon 2020 is a good example of these programs. You can also find more of them in our summary on the **"EU Guidance for barrier removal to river restoration"** (2021):

▸ *https://grueneliga.de/images/PDF-NewsletterENG/EEBguidanceBRRR-summarybroschure.pdf*

Turn the Vjosa to the first River National Park

The Vjosa River in Albania is one of the the last free-flowing rivers of Europe and is under great danger due to damming projects. Therefore a coalition of NGOs has launched the project **"Save the Blue Heart of Europe"**. You can support their campaign for the recognition of the Vjosa River as a National Park protected area, by signing a petition released in 2021:

▸ *https://www.change.org/p/vjosa-national-park-the-only-way-to-save-vjosa*

Living Rivers Foundation celebrating the migratory fish

In 2014 WFMF initiated the **World Fish Migration Day** (WFMD). This bi-annual event has a central message "Connecting fish, rivers and people" and is used to connect sites around the world. After fourth edition in 2020 the global reach is 200 million people through (social) media. By 2021 over 1,500 local events have been organized and over 5,000 organizations have been involved. The fifth edition was hosted in May 21, 2022. All organisations dealing with an interest in connecting rivers, fish and people are invited to host events at future World Fish Migration Days:

▸ *www.worldfishmigrationday.com*

On 11th of May 22 **Living Rivers Foundation**, **WWF Germany**, **Patagonia** and **flow:europe** organized a River Film evening as part of the **5th World Fish Migration Day** at the Patagonia Store Berlin.

Four short movies were presented, as well as the multi-award-winning documentary **"Was Fische wollen. Last chance for the Tyrolean Inn."** from Christoph Walder. This film illustrates the causes and the background of the dramatic decline of the Tyrolean Inn and gives a voice to the committed fishermen and conservationist fighting for the return of free-flowing rivers, but also reflects the views of hydropower operators. A trailer is available here:

▸ *https://vimeo.com/567821999*

Theresa Schiller (WWF Germany), **Tobias Schäfer** (WWF Germany), **Dr. Ruben van Treeck** (IfB: Institute of Inland Fisheries) and **Olaf Lindner** (DAFV: German Angling Association) had a discussion with the engaged audience on wild rivers, migratory fish and hydropower and highlighted the new Renewable Energy Sources Act, currently debated in the Bundestag. The Riverfilm event was moderated by **Michael Bender** (Living Rivers Foundation).

River Film Fest (Fluss Film Fest)

Living Rivers Foundation engages in the protection of free rivers and freshwater life, the sustainable management of water resources and the restoration of rivers landscapes – in Europe and internationally. Living Rivers Foundation is a supporter of the World Fish Migration Day and Dam Removal Europe by supporting campaigns, providing a science-policy interface and spreading the word. For more information follow this link:

▸ *https://www.living-rivers.eu*

The River Film Fest events present an international selection of environmental and outdoor films to celebrate free rivers, clean water and freshwater life. Together with various partners Living Rivers Foundation organizes events in Berlin, Germany and Europe to raise attention and inspire actions to protect our biodiversity and water in Rivers and Wetlands.

▸ *https://www.riverfilmfest.eu/*

Living Rivers Foundation
Berlin Office
Michael Bender,
10405 Berlin, Greifswalder Str. 4
phone: +49 (0)30 - 40 39 35 30
email: info@living-rivers.eu · website: www.living-rivers.eu

Editors: Michael Bender, Athénaïs Georges
Authors: Michael Bender, Athénaïs Georges, with contributions provided by World Fish Migration Foundation, Free Rivers Italy, WWF Finland; David J. H. Blake, Herman Wanningen, Pao Fernández Garrido and Elena Alfaya
Photo credits: Mikko Nikkinen, WWF Finland (title-page: Kangaskoski Dam on the River Hiitolanjoki, Finland), Claudia Kristine Schmidt (revers)
Layout: Jan Birk

This publication is funded by the Federal Ministry for Environment, Nature Conservation, Nuclear Safety and Consumer Protection.
The funds are made available by decision of the German Bundestag.
The responsibility for the content of this publication lies with the authors.

Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

Umwelt Bundesamt

June, 2022