ONEMA

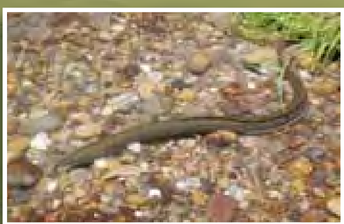
Meeting

Recap

Management plan to save the eel

Optimising the design and management of installations

Symposium on the results
of the Eels & Installations R&D programme
28-29 November 2011, Paris



Philippe Baran and Laurent Basilico

Management plan to save the eel

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Symposium on the results of the Eels & Installations R&D programme
28-29 November 2011, Paris

Philippe Baran (Onema) and Laurent Basilico (journalist)
in collaboration with Michel Larinier (Onema),
Christian Rigaud (Irstea)
and François Travade (EDF-LNHE)

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The symposium titled «Eels and ecological continuity. Optimising the design and management of installations» was organised by Onema (National agency for water and aquatic environments) and the steering committee of the Eels & Installations R&D programme.

It was held on 28 and 29 November 2011 in the auditorium of the Palais de la Porte Dorée in Paris, thanks to a partnership with the Tropical Aquarium.

This Meeting Recap document is available on the Onema site (www.onema.fr/synthese-anguilles-ouvrages) and at the national portal for «Water technical documents» (www.documentation.eaufrance.fr).

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Foreword

The European eel was until recently an abundant species in most European freshwaters, but its numbers have fallen sharply since the 1970s and 1980s. The causes of the rapid decline, which now threatens the very existence of the species, are clear for the most part and include fishing, poor quality of water and habitats, fragmentation of rivers by weirs and dams, and death in hydroelectric turbines.

To meet the restocking goals set by the European Union (EU), France has initiated a management plan addressing each of the factors responsible for the decline of the species. Concerning river obstacles and turbines, the Ecology ministry launched an R&D programme bringing together a number of partners, including Ademe, Onema and five hydroelectric companies, namely Compagnie nationale du Rhône, EDF, France Hydro Electricité, GDF Suez and Société hydroélectrique du Midi.

The programme, managed by a steering committee comprising the partners mentioned above and placed under the responsibility of the Ecology ministry, targeted a number of operational goals that resulted in the development and testing of technical solutions designed for rapid implementation in the field. All programme results were presented on 28 and 29 November 2011 at the feedback symposium which brought together 160 persons, including researchers, water managers, associations and hydroelectric companies.

How can the upstream migration of eels be encouraged, from the initial tide gates in estuaries up to and beyond the high dams located upstream? How can the conditions for downstream migration be improved at each installation? Finally, how can the cumulative impact of a series of installations along a river be calculated in order to adapt the management of hydroelectric turbines? These three questions are addressed in the three chapters of Part 1. Then the 16 datasheets discussing the operational results of the R&D programme are presented in Part 2.

Sommaire

A mysterious life cycle between the Sargasso Sea and inland waters

The Sargasso Sea, in the Northwest Atlantic, is the only known spawning zone for the eel. The months of March and April mark the high point in the reproductive phase and small transparent larvae, less than 7 mm long and called leptocephali, may be seen in and around the area from the end of February to the end of June. Their ocean migration is very passive and is currently estimated to last 18 months on average. Carried along by the favourable currents, they arrive near the European continental shelf where they metamorphose into glass eels, i.e. they change shape, lose water content, reduce in size and weight, and stop feeding.

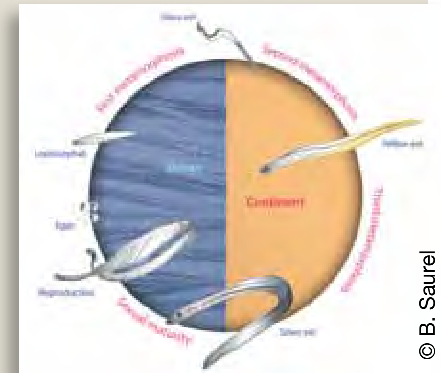
The glass eels enter estuaries in groups, carried by the tides. Some of the fish will remain in the estuaries and transitional waters, others will colonise inland waters during limited migratory periods (the «migration window» lasting approximately three months each year). During this phase, most of the fish are less than 30 cm long, with the average size of the migrators increasing with the distance from the tidal limit.

At some point, each fish halts its migration and settles in a favourable habitat for its growth. This may be in any type of inland waters. Sexual differentiation takes place when the fish reach the size of 20 cm. When its growth phase has terminated, the eel goes through its second metamorphosis that prepares it for the return to the sea. The males, which metamorphose at a size of between 27 and 45-50 cm, may be found in coastal and transitional waters, and in the lower sections of river basins. The females, which metamorphose at a size of more than 45 cm and sometimes more than 120 cm, may be found everywhere and are the only eels noted in the upper sections of river basins.

It is these «silver» eels that, in response to the autumn and winter flow pulses, race down the rivers to the sea and begin their 5 000 kilometre trip across the ocean to their birthplace in order to perpetuate the species.

This life cycle still harbours many mysteries, notably concerning sexual differentiation and the age at which the metamorphosis into silver eels occurs. It is now known that some eels spend their entire lives in the sea, but why and what proportion of eels do so in not known. Very little progress in the artificial reproduction and raising of eels has been made. These techniques are of little help in preserving the species which requires the mixing of millions of reproducers of various origins to maintain its very special characteristics.

The survival of the eel remains dependent on its capacity to travel freely up and downstream between the inland waters and the sea.



Life cycle of the European eel (source: Dekker, 2000).

A decline that calls for action

A rapid fall due to a number of factors

Just a few decades ago, the European eel (Anguilla anguilla) was abundant in most European inland waters. It could be found in small coastal rivers, in flatland rivers and often climbed to the upper reaches of river basins. The ubiquitous, wandering fish was also a common sight in marshes, canals and lakes, and even found its way to isolated ponds.

Since the beginning of the 1980s however, similar to its North-American and Japanese cousins, the stock has undergone a **rapid decline** that now threatens the survival of the species in many European river basins. The causes of the sharp reduction in numbers are, for the most part, well known. Similar to many other species living in European waters, notably diadromous fish, eels have suffered from the **degradation of its inland water habitats**. Intense fishing, increased human activities, the development and channelling of certain river sections, the draining of wetlands are all factors that weaken and fragment the eel's favourite habitats. In step with the development of industry and intensive agriculture, numerous **chemical pollutants** are released to the environment and downgrade the quality of inland waters.

For eels, which are a delicacy, **overfishing and poaching** are aggravating factors. That is particularly true for glass eels, juvenile fish caught with nets as they travel up through estuaries. They are an integral part of the culinary culture in certain regions and are also sold for monitored stocking purposes in certain water bodies.

Finally, various **installations** on rivers constitute an additional obstacle for the migratory species. During upstream migration, glass eels encounter a large range of installations in or near estuaries (flaps, locks, gates) that can restrict or block their access to inland waters. Further upstream, glass eels and elvers must face weirs and dams, notably hydroelectric installations, which, in the absence of special equipment, can represent obstacles very difficult to overcome. All of these more or less «passable» installations provoke concentrations of fish, of varying numbers and durations, that slow the progression upstream and result in higher mortality rates due to predation, fishing and the consequent health problems. Years later, when the adult females set off to the ocean, the hydroelectric installations along rivers again cause high, cumulative mortality rates because, depending on the type of installation and its configuration, the fish can pass through the turbines.

Recent recognition in public policies with the European regulation and the French management plan

The IUCN has listed eels as a species threated with extinction and they are now protected by an EU preservation policy. In September 2007, the European Union voted a regulation (EC 1100/2007) setting up measures for the recovery of the eel stock. This legal obligation requires that each Member State establish an eel-management plan to reduce anthropogenic mortalities so as to permit with high probability the escapement to the sea of at least 40% of the silver eel biomass relative to the best estimate of escapement that would have existed if no anthropogenic influences had impacted the stock.

In France, the EU regulation resulted in a **management plan**, formulated by the Fisheries and Ecology ministries, structured along river-basin lines. The French plan, approved by the European commission in February 2010, comprises several sections addressing each of the factors causing the decline in eel stocks, e.g. fishing regulations, efforts against poaching, development work on installations, restocking of rivers and improvements in water quality. Each of these aspects is presented in a brochure published by Onema in October 2010 (downloadable from www.onema.fr/Plan-anguille-approuve).

In terms of fishing, the management plan sets up quotas for the commercial fishing of glass eels, forbids the capture of yellow eels over several months of the year, forbids virtually all captures of silver eels and also severely regulates amateur fishing, including an interdiction of night fishing and the capture of silver eels. The goal is to reduce captures by 60% at each stage in the eel life cycle by 2015. The management plan also stipulates that by 2013, 60% of the glass eels caught in France must be used for restocking programmes in Europe, including 5 to 10% for French river basins.

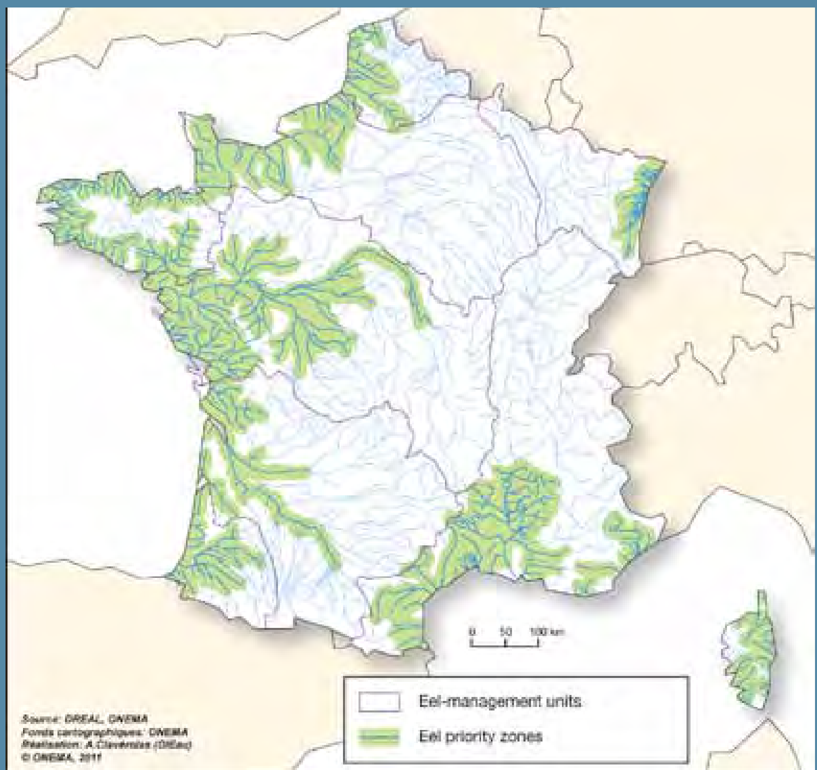
Projects to limit the impact of wiers and dams

The goal of the «installations» part of the management plan is to improve the capacity of eels to travel up and down French rivers. These projects concern the upstream migration of glass eels and yellow eels, but also of course the downstream migration of silver eels that risk injury or death if they pass through hydroelectric turbines. Concerning downstream migration, the objective of the French plan is to achieve escapement of 40% of the silver-eel biomass relative to that which would have escaped if no anthropogenic influences had impacted the stock.

To that end, it was deemed necessary to focus efforts initially on equipping those installations offering the best cost-effectiveness ratio in terms of eel protection. The State services carrying out this analysis identified priority zones (see figure 1) in which all installations must be evaluated and, if necessary, modified to ensure safe passage in both directions by 2015. The priority zones comprise a total of 1 555 identified

Figure 1. La zone d'action prioritaire du volet «ouvrages» du plan national de gestion de l'anguille.

Priority zones for the eel-management plan



installations, including 223 hydroelectric plants.

To facilitate upgrading of installations within five years, the management plan also established a classification system, whereby each section of all French rivers was assigned to either one or both of two categories (Lists 1 and 2). For the sections in List 1, defined as those requiring complete protection of migratory fish, no new obstacles to ecological continuity may be created. Classification in List 2 means that all installations must be upgraded to comply, within five years, with current standards in terms of their management, maintenance and equipment.

Success will of course depend on the capacity of stakeholders to identify, for a given river and/or installation, the technical solutions offering the best cost-effectiveness. Prior to the management plan, most efforts in favour of eels had dealt with systems for the upstream migration of glass eels and elvers. Since the 1990s, a number of installations have been equipped with fish passes outfitted with special surfaces (studs, brushes), notably in river basins along the Atlantic coast and in southwest France. According to the management plan, these existing solutions must be re-evaluated and, if necessary, improved. But above all, solutions must be expanded and widely implemented to cover all types of obstacles and to include downstream migration of silver eels to the sea.

That was the goal of the Eels & Installations R&D programme set up by the

Eels & Installations R&D programme, a partnership

Over a period of three years, the R&D programme, with support from Ademe, brought together Onema and five hydroelectric companies, namely Compagnie nationale du Rhône, EDF, France Hydro Electricité, GDF Suez and Société hydroélectrique du Midi. Both along rivers and in labs, over 50 technicians and researchers successfully completed a set of 16 research projects targeting highly operational results.

Table 1. The 16 coordinated research projects in the Eels & Installations R&D programme (the project numbers correspond to the list contained in the framework agreement).

Project	Data-sheet (Part 2)	Title	Scientific directors
9	1	Development of a sampling protocol to determine eel downstream-migration rhythms in the Dordogne river	Laurence Lissalde-Bonnet (EDF-CIH)
10	2	Determining how eels overcome a series of obstacles on the Rhine	Éric de Oliveira (EDF R&D – LNHE)
7	3	Study of eel downstream migration and passage of hydroelectric installations on the Gave de Pau river	Michel Larinier (Onema), Philippe Baran (Onema), François Travade (EDF R&D)
2	4	Capture-mark-recapture and evaluation of the effectiveness of a specific type of fish pass	Christian Rigaud (Irstea), Hilaire Drouineau (Irstea), Philippe Baran (Onema)
4	5	Development and testing of an automatic resistive counter for elvers	François Travade (EDF R&D)
5	6	*In situ* evaluation of eel mortality in large turbines	Éric de Oliveira (EDF R&D – LNHE), Franck Pressiat (CNR Ingénierie)
6	7	Models to predict eel mortality during transit of Kaplan turbines	Peggy Gomes (Onema), Michel Larinier (Onema)
15	8	Evaluating the cumulative mortality over entire river sections caused by hydroelectric installations during the downstream migration of silver eels	Peggy Gomes (Onema), Michel Larinier (Onema), Philippe Baran (Onema)
16	9	Predicting numbers of downstream migrating eels as a function of environmental factors and development of an operational prediction model for turbine management on the Loire river	Anthony Acou (MNHN)
1	10	Winter management of tide gates for eels	Christian Rigaud (Irstea), Philippe Baran (Onema)
3	11	Test of a brush pass for eels at a high dam (Golfech on the Garonne river)	François Travade (EDF R&D)
8	12	Test of the MIGROMAT® biomonitor on River Shannon (Ireland)	Michel Larinier (Onema), François Travade (EDF R&D)
11	13	Test of an infrasonic repulsion device at two hydroelectric plants on the Gave de Pau river	Michel Larinier (Onema), Philippe Baran (Onema), François Travade (EDF R&D)
12	14	Determining the necessary conditions for fish-friendly water intakes. Head losses with inclined and angled screens, and velocity profiles just upstream	Laurent David (Institut P'), Ludovic Chatellier (Institut P'), Dominique Courret (Onema), Michel Larinier (Onema)
13	15	Assessment of injuries suffered by eels migrating downstream during passage through the new VLH turbine with a spherical runner housing, installed on the Moselle river	M. Larinier (Onema), Lagarrigue (ECOGEA)
14	16	Contribution to developing the Alden fish-friendly turbine	François Travade (EDF R&D)

Ecology ministry in support of the French management plan for eels.

The R&D programme, with the 16 coordinated research projects (see table 1) carried out from 2009 to 2011 with a total budget of 4.5 M€, was a key component in the national management plan. It produced significant progress in understanding eel behaviour in and around installations, in quantifying mortality rates for each type of installation, in diagnosing impacts along entire river sections and, finally, in devising, testing and validating equipment and technical solutions. These results, based on a fruitful partnership between Onema, Ademe and the hydroelectric companies, are presented briefly in this first part of the document. The projects are also presented in greater detail in the datasheets in Part 2.

De la recherche à la mise en œuvre opérationnelle : concertation et stratégie de territoires

The 16 research projects in the R&D programme produced new knowledge, solutions and operational tools that pave the way for a collaborative response by the economic participants to the challenge of restoring the species. During the three years of work, the programme partners tested a wide range of techniques, determined their usage conditions and eliminated a number of unsatisfactory methods. This new knowledge has put the «installations» part of the eel-management plan in a position to shift rapidly to operational deployment. Starting with a diagnosis approved by all participants, selection of technical compromises must take into account a cost-effectiveness analysis specific to each installation. The issues concerning the funding for development work now require clear answers, a fact that was emphasised during the discussions between the various participants (water managers, local governments, hydroelectric companies) during the final round table of the symposium.

FIn light of the ecological crisis and the legal obligations, a condition for success lies in maintaining consistency between the diagnosis, operational decisions, their implementation and monitoring. It is through concerted implementation by the various participants and on the different management levels, ranging from individual installations to entire river basins, that the solutions presented here will contribute to the stock-recovery goals set by the public authorities. The collective effort must be based on a suitable method. Analysis of that method was launched by the members of the steering committee for the R&D programme during a meeting just after the feedback symposium.

All issues dealing with the management and restoration of ecosystems must first be addressed on the territorial level. For example, concerning installation impacts on eel migration, it would appear necessary to first define the most relevant territory for diagnostic studies before deciding on any necessary work. The priority zones presented above are «technical» territories that serve to focus efforts on equipping those installations offering the best cost-effectiveness ratio in terms of eel protection. However, though such zones are indispensable regulatory and operational tools, they must not become limits when preparing projects to restore eel stocks.

It is on the scale of entire river basins that eels colonise freshwaters during migrations that condition their distribution in inland habitats. And it is consequently on the same scale that local development and management projects for installations should be designed to optimise eel upstream migration and settlement in the most favourable habitats, and then their downstream migration.

In each territory, project implementation must also be based on a mobilisation of all stakeholders, i.e. water managers, local governments, fishing associations and companies, State services, potential sponsors, etc. The steering committee of the R&D programme recommends organising stakeholder meetings before launching a project to provide each participant with an identical, clear vision of the issues, notably through information on the latest technical and scientific progress.

It would appear particularly useful to create a «group» (the precise form depends on the local conditions) to bring together periodically all the participants willing to engage in projects. The meetings are an occasion to share information on assessments, methods and results. The group must be led and managed by a project leader who is considered legitimate by all members, under the responsibility of a representative monitoring committee. This type of coordinating group must of course work in conjunction with the existing entities (local water commissions, river committees, etc.) and processes (RBMPs, sub-basin management plans, basin contracts, environmental contacts). The group must oversee the design and implementation of an integrated set of priority projects spanning the entire territory.

Part 1

Diagnosing impacts and implementing technical solutions

1 **Upstream migration, installations,**

their effects and technical solutions

On arriving at the European continental shelf after a seven to nine-month journey, eels undergo their first metamorphosis, i.e. the leptocephali, similar in shape to willow leaves, stop feeding and become glass eels with a cylindrical body approximately 75 mm long on average. Attracted by the plumes of brackish water, the fish concentrate at the entry to estuaries and then cross the tidal limit. It is the start of their migration up through river basins that will end with the glass eels, and subsequently the yellow eels, settling into the habitats where they will spend most of their lives. This upstream-migration phase obviously determines their distribution in a given river basin. The presence of a large number of installations in a river, from the tide gates to dams located further upstream, can constitute serious obstacles to the upstream migration of eels.

Following a review of current knowledge on the behaviour and the biology of the species during upstream migration, this first chapter will present the results of the R&D programme in terms of installation impacts on this critical migration and describe the proposed systems and technical solutions to improve installations and their management.

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1.1 – Upstream migration and colonisation, a crucial factor for the survival of the species

The colonisation phase determines the distribution of eels in the various habitats of a river basin. Virtually no information on the biology of elvers during upstream migration and the links with installation issues was available until recently. The rapid drop in eel numbers has turned the topic into a subject of increasingly intense study facilitated by the development of new research tools such as micro-chemistry of bones and muscle, genetics, physiology, markers and behavioural monitoring, evaluation of fish passes, statistical analyses and modelling.

Prior to the *in situ* experiments for the R&D programme, a panorama of current knowledge was drafted on the basis of 110 bibliographical references, drawn primarily from French work on the topic, and presented by Christian Rigaud (Irstea, Ecohydraulic centre) and Philippe Baran (Onema, Ecohydraulic centre) during the feedback symposium held on 28 and 29 November 2011.

Upstream migration and colonisation, the decisive phase for species distribution

Following a journey across the ocean lasting over a year and a metamorphosis, the transparent glass eels stop feeding. Drawn by the plumes of brackish water, they approach and then enter estuaries, carried by the tidal currents. The fish rapidly come into contact with freshwater and are confronted, depending on the period and the site, with highly variable transitional or estuarine environments (varying differences in high and low tidal levels, varying haline stratification, changing relations between tidal forces and river flow rates).

Their entry into estuaries takes place in successive waves over several months, for example from November to April along the Atlantic coast. Each fish acquires enhanced pigmentation at a rate that depends on the water salinity and temperature (over 45 to 60 days on average), and begins feeding

again about half way through the pigmentation process.
This phenomena modifies the behaviour of glass eels in the tidal zone. During this initial phase, they are essentially pelagic, which makes them vulnerable to nets. Given their depleted physical capabilities, progress through the estuary depends on their capacity to deal, more or less effectively, with the high-tide currents. During the ebb tide, some glass eels flow back with the tide whereas others rapidly find a niche along the bottom or the banks and wait for the next high tide. This phenomena is called selective tidal transport. Once they have started feeding again, the pigmented glass eels adopt a more autonomous (active swimming over long periods) and ben-thic behaviour. Depending on the date of its entry in the estuary and its activity during the pelagic phase, the shift in the behaviour of the juvenile eel takes place at a more or less early date (in December for the first arrivals) and at a spot more or less upstream in the estuary. The time and position of the change in behaviour most probably has a significant influence on the future of each fish, i.e. whether they settle in a saltwater or brackish zone, or continue to migrate to inland waters, their eventual size, etc.

Generally in the beginning of spring, when strong tides occur and water temperatures increase significantly (above 11 to 12°C), some juveniles, attracted by the freshwater, cross the changing tidal limit and start off on their migration against the current toward the upstream sections of river basins. Most of the fish are less than 30 cm in length. Their size increases and their numbers decrease with the distance covered since the tidal limit. The migration takes place during a spring and/or summer «migration window» of approximately three months that remains fairly constant for a given site. The period shifts in step with the distance from the tidal limit.

Similar to the initial estuary phase, the behaviour of individual fish during the migratory phase differs in that they can travel more or less far and halt in highly diverse habitats. Once the fish has stopped migrating (sometimes during the first year, occasionally after several years), it becomes more sedentary and begins regularly to explore the area around its home. The size of the explored territory increases with that of the eel. Moves over fairly short distances (much shorter than the migration) take place only if special events occur (e.g. a drop in environmental quality, flow pulses, etc.).
On the whole, it is clear that because the upstream-

migration phase starts in the tidal zone and, for some of the fish, continues with active travel upstream against the river current, it is the decisive factor in the distribution of eels throughout the river basin. This distribution in turn determines the later characteristics of silver eels because their subsequent growth, survival rate and overall quality depends on the habitats where they settle.

The presence of a large number of installations in French rivers, from the tide gates in estuaries and transitional zones to dams located further upstream, can create serious disturbances by slowing or even blocking migration over a more or less long period. The distance covered during the migration window is, of course, impacted and mortality rates rise because the fish remain blocked at least temporarily downstream of installations, thus becoming subject to pathologies, predation, cannibalism, fishing, etc. The latter aspects have rarely been quantified to date.

Swimming behaviour and general implications for installation design

The juvenile stages, i.e. glass eels and yellow eels up to 30 cm, adopt a fairly well known set of behaviours during travel that must be taken into account in order to adapt installations to their upstream migration. Eels are drawn by «attractive flows», but are limited in their capacity to swim against them. Glass eels cannot swim faster than 0.1 to 0.2 metres per second for a sustained period, with a maximum speed of 0.3 to 0.5 m/s for brief sprints, while elvers reach speeds of only 0.3 to 0.6 m/s. Consequently, when migrating upstream,

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eels make use of any irregularities in the river bed or along the banks. Travel is facilitated by the «boundary layers», i.e. velocity gradients in the flow around obstacles, with frequent pauses in resting zones along the banks. The fish can also bury themselves periodically if the substrate is sufficiently loose.

Generally speaking, the flow rate of a river plays a major role during the colonisation phase. It stimulates migration, determines the timing of access to certain river sections or to certain installations affected by tides, and can under certain conditions slow the progress of the migrators.

These elements must be taken into account:
- during the design phase and positioning of fish passes which work better if they are located near the main currents downstream of an installation;
- but also during operation of a fish pass because it is the existence of a significant attractive flow along the migratory path that stimulates migratory behaviour and consequently the effective use of fish passes.

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Eels are capable of climbing up wet substrates offering sufficient support and where currents are not too strong. The angle of the passable slopes declines with the size of the fish (vertical climbs of up to 9 cm are possible). These factors, confirmed by observations in experimental situations, determine the design of brush and stud passes. For example, slopes never exceed 45° and flow rates are very low.

Work has also been carried out on the attractiveness of fish passes. The odour of the water passing through the lower section of the pass is now recognised as important, for example, passage through the upstream trap basin is a positive factor. Some turbulence at the foot of the pass is also favourable because the roiling water and the noise help in locating the entry of the pass. On the other hand, little work has been done to date on the number of special passes (generally narrow ramps) required depending on the size of an installation.

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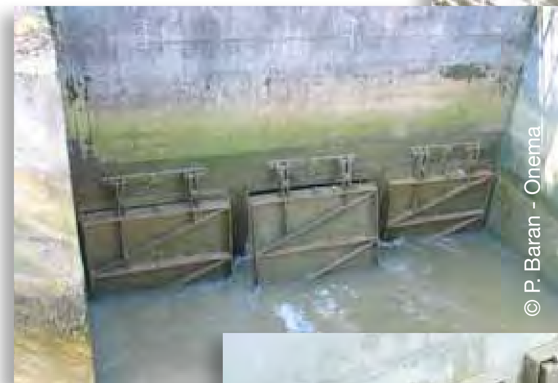
1.2 – Tide gates, their impact and the solutions

In estuaries, the tidal zone, i.e. the unstable interface between the saltwater and freshwater environments, concentrates a number of important human activities, including aquaculture, fishing, boating, agriculture and tourism. In France, a large number of installations have been created, along the main river channels or along tributaries, to supply salt marshes located behind levees, to limit the penetration of sea water upstream and/or to limit the regular flooding of upstream land with saltwater. Often very small in size and rarely listed among the 60 000 installations in the national database on river obstacles, they serve for a wide variety of situations and uses. Highly diverse in design, they may be installed anywhere from the lower sections of estuaries, dominated by marine influences, to the mouths of rivers subject to freshwater «tides». The typology established for the R&D programme distinguishes between tide gates, flaps and crest gates (single or double channels), rising sector sluice gates, hydraulic flaps and navigational locks, which can all be combined in various configurations. Their mode of operation can hinder the free movement of juvenile eels toward useful habitats, e.g. main river sections and smaller tributaries, canals, marshes and wetlands.

Test on winter admissions of sea water in the Charente estuary

This diversity obviously complicates efforts to analyse their effects on the upstream migration of glass eels and to devise solutions to reduce those impacts. In France, tests have been carried out or are now underway, thanks to associations for migratory animals (*Logrami, Migado, etc.*), local entities (*IAV, Brière nature park, Marais Poitevin regional park*), engineering firms (*Ecogea, Fish Pass*), university research teams



(*Rennes University, Agro Rennes*) and Onema.

In the R&D programme, one project evaluated the effectiveness of a management system attempting to restore hydraulic continuity between upstream and downstream by admitting sea water upstream during the winter. The study (Ch. Rigaud, Irstea, Ph. Baran, Onema) was carried out at Charras, on a site in a typical, downstream estuarine environment. Located on a tributary to the Charente estuary, the installation comprises two tide gates downstream and a double crest gate upstream. It is used to manage 235 square kilometres of river basin and freshwater marshes. Over the 2010 and 2011 winters, the scientific teams tested on site a technical solution used by the installation manager (UNIMA, the Charente-Maritime union of marsh managers). In the downstream section, a 10-cm wooden chock inhibited complete closing of one of the tide gates and, upstream, water was admitted either over or under the crest gate.

Eight measurement campaigns were carried out, each comprising four successive high tides (two by day and two by night). During each high tide, biological samples were drawn every 20 minutes, both upstream and downstream of the installation, to monitor changes in the numbers of glass eels. The upstream and downstream water levels and the salinity levels were monitored continuously. In addition, quantitative evaluations of suspended matter were carried out during four high tides.

The glass eels arrive at the tide gates almost simultaneously with the saltwater, with the highest numbers occurring between 150 and 90 minutes before the high tide. However, the quantities vary significantly over the migratory season. This variability in numbers, due to the strength of tides and river flow rates (see figures 2 and 3), would argue in favour of continuous, limited admissions, which would also encourage stable hydrological operation in the area rather than two or three massive admissions of saltwater over the year.

During the 32 high tides covered by the project, 52 kilograms of glass eels passed through the installation. As expected, a majority (70%) took place at night. Significant differences were observed between the two types of admission at the upstream gates, as shown

Figures 2 and 3. Density of glass eels downstream of the installation as a function of the canal flow rate and the strength of tides, over two consecutive years (Lamarque *et al.*, 2012).

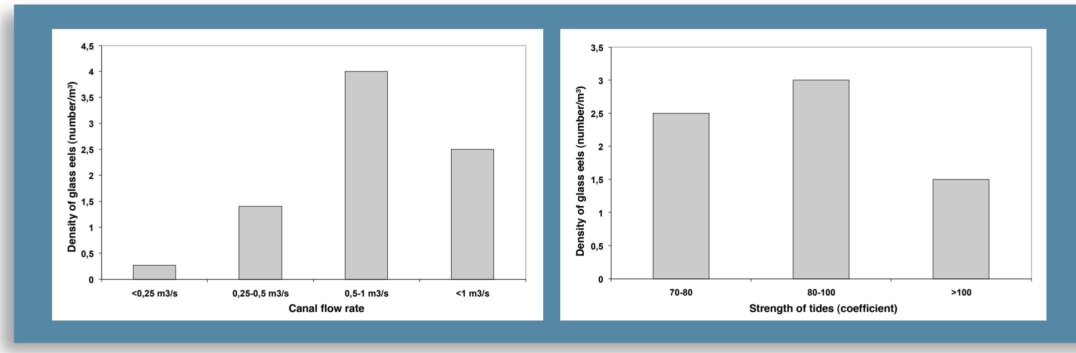
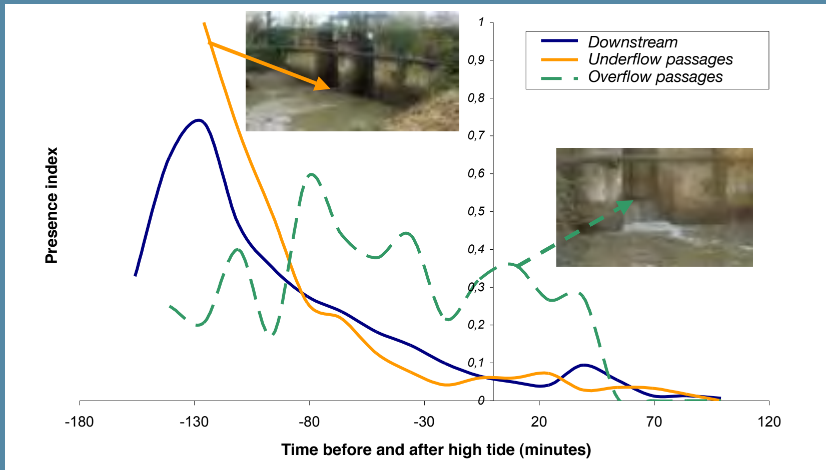


Figure 4. Presence of glass eels downstream and at the upstream gate, for both underflow and overflow passages.



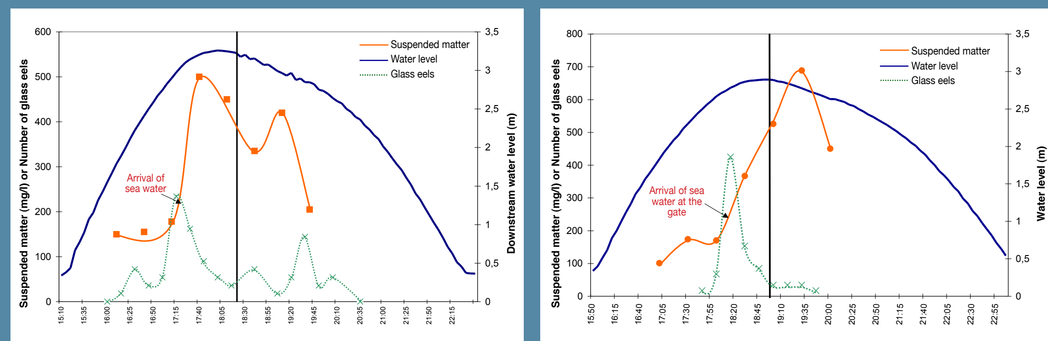
in figure 4. The numbers of glass eels transiting the gates was 37% higher for underflows than for overflows. The difference is even greater at night. Passage flow dynamics also differed. During the underflow admissions, the number of passing eels was similar to the number of the eels arriving from downstream, with maximum numbers passing when the sea water arrived (with 75 % of passages in one hour, between 150 and 90 minutes before high tide). In comparison, overflow admissions resulted in a delay in the passage of glass eels. Passages occur 30 to 60 minutes after peak numbers arrive at the obstacle and are less concentrated.

The *in situ* observations were also an occasion to collect data on the influence of environmental parameters on the migratory behaviour of glass eels. This behaviour would appear to depend heavily on the density of suspended matter in the water. Passages peak with the arrival of the sea water, i.e. with the beginning of the increase in levels of suspended matter, as shown in figure 5.

Finally, the study characterised the influence of the structure of the installation, and consequently any modifications in its operation, on the salinity of the water in the upstream reach (7 km long and 12 m wide). In 50% of cases, the volumes of saltwater admitted represented 40% of the water volumes accumulating upstream of the installation during high tides, with an increase of five centimetres in the water level. This 40% ratio depended on the tidal coefficient, weather conditions, the management system of the installation and the upstream flow rate in the canal. The quantities of freshwater in winter varied between 0.3 and 8 cubic metres per second, with a median value of 1.3 m^3/s.

Changes in salinity and suspended-matter values upstream of the installation fluctuate with the tides. On the whole, in a vast majority of cases, flows of salt and suspended matter upstream fall to zero at the end of each tidal cycle. The salt and sediment that entered with the high tide leave with the ebb. The change in salinity upstream can be influenced by the arrival of freshwater. When the flow rate is low (0.25 m^3/s), salinity can increase up to three times higher than the normal level. Such a high salinity level, which occurred briefly in April 2011, can cause problems for upstream uses of water.

Figure 5. Glass-eel passages and suspended-matter concentrations during two diurnal tides (Lamarque *et al.*, 2012).



Operational outlook

The study at Charras confirmed the usefulness of modifications to enable the entry of sea water upstream. They can be implemented rapidly, at little cost, are reversible and result in large numbers of glass eels passing the obstacle, notably during the winter. On the basis of the on-site observations, limited but regular admissions are preferable to a small number of massive admissions.

Actual implementation of this type of solution must be based on an analysis of the installation, its operation and on how the upstream reach is used.

- For installations regulating saltwater zones upstream, water may be admitted all year long. The only possible constraint lies in the risk of flooding.
- For installations farther upstream in the estuary, the low salinity level of the water arriving at the installation generally makes regular admissions possible, at least until the beginning of summer.
- For installations at the downstream end of freshwater zones, analysis is required to determine the permissible volumes of salt water admitted upstream, given the constraints in terms of upstream usage, suspended matter and/or flooding.

In all cases, the analysis must also address the potential of upstream habitats for colonisation and identify any problems, e.g. regular dry periods, acute pollution, etc.

On the condition that modifications to the installation are relevant and compatible with its purpose, a number of technical solutions are available.

- Tide gates. Small doors may be installed in the gates. Their size and position are determined by the quantities of sea water to be admitted upstream. Their position is also determined by the behaviour of the glass eels in the area and particularly their position in the water (at the bottom or the surface). If small doors are not a feasible solution, chocks at least 10 cm in size may be inserted to inhibit complete closing of the gate.
- Flaps. Modifications may make it possible to maintain a limited opening during the rising tide or to delay closing.
- Locks. Locks can be used in the winter with two phases, filling of the lock and admission upstream.

When tide doors are coupled with crest gates upstream to regulate the outflow of freshwater, underflow passage through the latter is preferable. A fairly short distance (< 100 metres) between the two does not represent a serious obstacle for the glass eels.

Capture-mark-recapture and evaluation of the effectiveness of a specific type of fish pass

Similar to the above study, efforts undertaken to evaluate the effectiveness of a fish pass commonly encounter the difficulty of precisely determining the number of glass eels arriving at the downstream entry point. To obtain reliable, quantitative results, the best solution remains a capture-mark-recapture (CMR) system. This technique on an equipped site consists of releasing a known number of marked fish at different spots downstream of an installation, then observing how many make their way to the fish pass and the flow dynamics of their travel. This strategy depends on the marking technique having a minimal impact on fish behaviour. This technique, costly in terms of time and energy, is particularly suitable for installations located in estuaries or near the tidal limit where there are large numbers of eels showing clear migratory behaviour, i.e. areas having a major effect on subsequent colonisation.

Various methods have been used to test this behaviour, depending on the size of the monitored fish. Since 1999, the Migado association (Lauronce *et al.*, 2011) has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pit-tagged (a tag with an electronic ID code) 10 300 eels 25 to 35 centimetres in size at the EDF Golfech and Tuillières dams and released them two to three kilometres downstream. Recaptures span long periods (up to seven years after marking) and the annual probability of recapture varies depending on the site and the year. These results indicate travel based more on trial and error depending to the given conditions than a pressing need to migrate.

Another technique (Christian Rigaud, Irstea, Hilaire Drouineau, Irstea, Philippe Baran, Onema) was tested in the R&D programme, using VIE (visible implant elastomer) tags. These tags are suitable for small eels up to 15 cm in length and have been tested to ensure minimal impact on fish behaviour (Imbert *et al.*, 2007). In 2009 and 2010, the technique was employed on three sites equipped with special eel passes. Two of the sites are subject to tides (Riberou on the Seudre river, Enfreneaux on the Sèvre niortaise river) and the third is located four kilometres upstream of the tidal limit at Pas du Bouc on the Porge canal.

The research teams carried out a total of 16 campaigns on these three sites. Almost 10 000 VIE-tagged fish were monitored. The campaigns focussed on the three-month migration window that was determined thanks to the very regular monitoring carried out at the installations by the operator (fishing federations of the Charente-Maritime and the Gironde departments, Marais Poitevin regional park).


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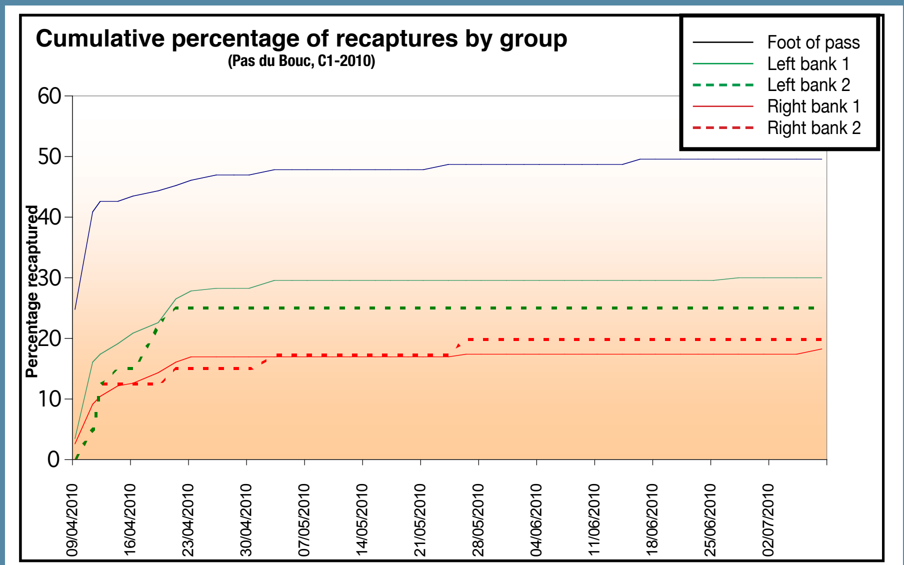
An identical protocol was used for each campaign, i.e. 600 fish drawn from the trap basin were examined (size, weight, health status), then marked and placed in three groups. The first was released at the foot of the fish pass, the two others were released about 50 metres downstream, one near the left bank, the other near the right bank. Following the release, the fish caught in the pass traps were systematically checked for fluorescent markings using an UV lamp (resulting in processing times 50% longer than for standard procedures). The marked fish were then measured and examined prior to being released well upstream of the installation. A control group (marked and unmarked) was held in observation for six days. The mortality of the marked fish was always under 1%.

On each of the three sites, a majority of the upstream recaptures took place within ten days. Figure 6 shows the cumulative percentage of recaptures as a function of the release point at the Pas du Bouc site. The recapture chronology of the various groups was fairly similar on all three sites. Analysis of the recapture quantities for the downstream groups and the comparison with the groups released at the foot of the pass revealed significant variability between sites and within sites, which may be explained by different operating situations, differences in the resumption of migratory activity depending on the campaign and different levels of access to the fish passes not only between sites, but also over time.

Figure 6. Cumulative percentage of recaptures as a function of the release point at the Pas du Bouc site (Rigaud *et al.*, 2012).



On the whole, it would appear that following a marking operation, not all the fish released at the foot of the fish pass immediately resume their migration. To determine the relative importance of the various factors influencing the capacity of the eels to transit a fish pass, Bayesian analysis was used on the Pas de Bouc site for which the data was the most complete. The model used a time step of one day over 12-day series and took into account the size and condition of individual fish, their point of release, daily changes in water depth, temperature, cloud cover, day in lunar month, etc. The study clearly identified a higher river flow rate as a factor that facilitates transit through the pass in that it increases the probability of reaching the foot of the pass for the groups released downstream.

The model will be adapted and tested in the two estuaries (Ribérou and Enfreneaux) and may be used again in other operations on the same site.

This project produced initial results concerning the effectiveness of fish passes designed specifically for elvers. The level of effectiveness, which varies from 22 to 41% depending on the study site, depends heavily on the environmental conditions. The project also demonstrated both the value of the tested CMR strategy in evaluating the upstream transitability of an installation and its capacity to supply useful data providing new information on the local migratory behaviour of elvers in view of making changes in installations. The constraints inherent in the technique (long marking operations and subsequent identification of the fish in the trap) mean, however, that its use will be limited to a few test sites. In terms of the overall method, an inspection cage to detect any direct mortalities would appear indispensable. Also of great importance is the release of marked groups at the foot of the pass. Finally, the analysis of the results for this type of project must take into account changes in the level of migratory activity of the eels during the monitoring periods.

1.3 - Easier passage of large dams

Upstream of estuaries, on larger rivers, elvers migrating upstream can encounter another type of installation that is difficult or even impossible to overcome, i.e. high dams. For decades, various systems (fish passes, elevators) have been installed on many dams to restore ecological continuity. They were poorly suited to small eels, however, and other passes specifically for eels were installed with inclined substrates (brushes, studs) and low flow rates. For the eel-management plan, a re-evaluation of the operation and the effectiveness of these special passes was deemed indispensable, notably given the results of a study from New Zealand on passes for very high dams, which revealed that many eels tend to turn back downstream before reaching the top of the pass.

Brush passes and
cut-off basins

A project (François Travade, EDF R&D) in the R&D programme was conducted over three migratory seasons (May to July) on the eel pass at the Golfech hydroelectric plant on the Garonne river. It was run by the Migado association with EDF R&D. In 2002, the high dam (17 metres of head) was equipped with a brush pass to compensate for the existing fish elevator that had proven ineffective for eels. From 2002 to 2008, only the lower section of the pass was built. It led to a trap basin and the eels were then transferred manually upstream.

In 2008, the pass was completed to the top of the dam. The goal of the project was to evaluate the effectiveness of a «cut-off basin» to block return travel downstream, located at about one third of the total height. The lower section of the pass (7 metres of vertical gain) is installed around the bottom part of the fish elevator and empties into the cut-off basin. The upper section (10 metres of vertical gain) climbs from the cut-off basin to the canal leading from the elevator to the river upstream. Both sections have a flow rate of 2.5 litres per second. Rest basins are inserted at regular intervals.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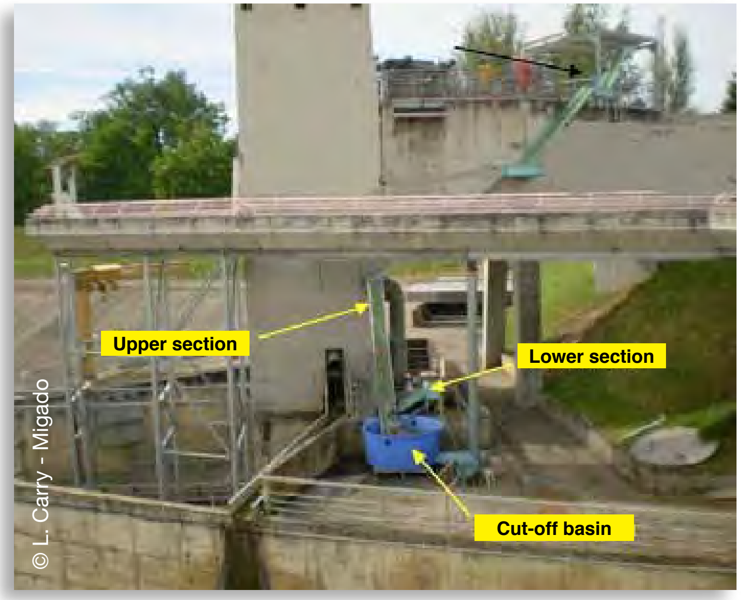

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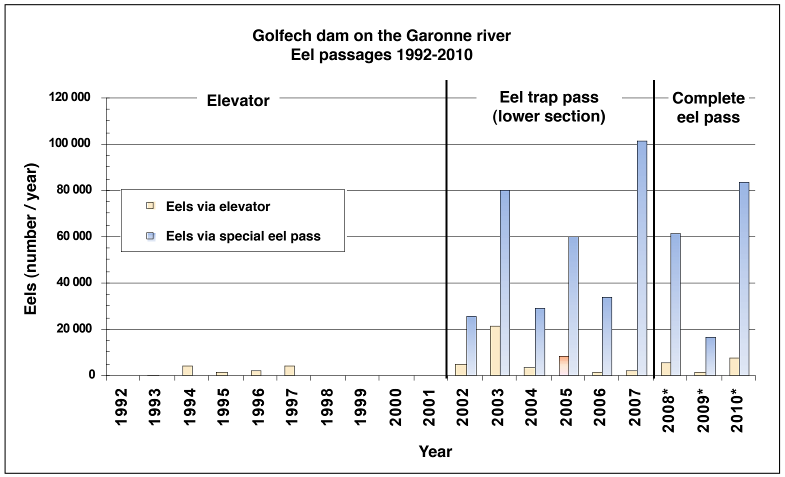
To monitor the behaviour of the fish in the pass and detect any accumulations of fish in the cut-off basin, a number of elvers were captured and equipped with transponders. Three transponder data recorders were installed on the lower section, at the foot of the upper section (the exit of the cut-off basin) and at the head of the upper section respectively. At the same time, an automatic resistive counter to quantify the number of elvers reaching the summit was tested at the top of the pass.

The results confirmed the value of the cut-off basin. Approximately 50% of the tagged eels that started up the upper section returned to the cut-off basin (between 1 and 19 times). The time spent in the cut-off basin was relatively short, less than 40 minutes for 86% of the eels, and no «abnormal» accumulation of fish in the basin was observed.

Figure 7. Number of eels passing the EDF Golfech dam on the Garonne river from 1992 to 2010.
Up to 2001, fish elevator alone.
2002 to 2007, addition of a special trap pass for eels with manual transfer to the top.
Since 2008, complete eel pass with cut-off basin.



The quantitative results (figure 7) showed that the annual passage rates were comparable to those observed up to 2007 using the laborious pass trap located at one-third the total height and which required manual intervention to carry the fish to the top.

The tagged eels took 2.5 hours on average to travel the upper section. Half of the fish reached the top in less than one hour and the maximum time did not exceed 24 hours. Similar to the trap pass tested up to 2007, a majority of passages took place at night with the peak number between 22.00 at night and 6.00 in the morning. However, with the new cut-off basin installed, a larger percentage of passages was diurnal, ranging from 24 to 54%, depending on the year. This may be due to the round trips undertaken by the eels in the upper section of the fish pass.

Accumulations of fish were noted at the head of the pass. The accumulations were likely due to their fear of dropping off the end of the ramp. The researchers modified the Fish Pass system by extending the top of the ramp with a section slanting downward, thus enabling the elvers to slide down from the top. This modification significantly reduced the accumulation at the head of the ramp.

One major problem noted by the researchers concerned predation by birds. The rest basins and ramps were attacked, notably by herons and gulls, making it necessary to protect the entire pass with screens.

In conclusion, the special passes comprising ramps equipped with a substrate to assist the fish in crawling up proved their usefulness in overcoming dams, even very high dams (20 to 60 metres high). To ensure optimum effectiveness, it is advised to install a cut-off basin in the lower section to prevent return travel. It is also recommended to facilitate exit of the eels at the top of the pass. Finally, it is absolutely necessary to protect the pass against predation by birds.

Development and testing of an automatic resistive counter for elvers in a brush pass

In addition to manual counting of the eels in the pass traps at the Golfech dam, a related project in the R&D programme developed and tested an automatic resistive counter (François Travade, EDF R&D). This type of system offers a double advantage. It requires less labour and also provides more detailed information on upstream-migration rhythms of eels. This information is useful in terms of the biological data collected and for evaluating the effectiveness of any modifications made to an installation.

The system tested on the Golfech eel pass was developed in 1997 by the ELTA company (formerly ELFES), at the request of EDF R&D. The counter was put through *in situ* tests and progressively developed and upgraded until the final version was produced in 2007. The technique is based on the difference in conductivity between fish and water. The fish are counted and their size is determined automatically by analysing the variations in conductivity detected by electrodes positioned in the water along the path followed by the fish. On arriving at the top of the pass, the eels slide down into a reception tank and then through one of four tubes supplied with water (0.1 litre per second) and equipped with electrodes. The system continuously records the water temperature and time-stamps each passage. It is capable of distinguishing between two sets of sizes (adjustable) and can be remotely polled by telephone (GSM).

At Golfech, the tests were run over three migratory seasons (May to July) from 2008 to 2010 and the final results confirmed the effectiveness of the system.

A total of 38 000 fish were counted in 2010 and 59 000 in 2008, with daily peaks above 11 000 fish and hourly peaks of approximately 1 600 fish. The collected data made it possible to plot the migratory periods over the year (figure 8) and to determine hourly passage rates (figure 9).

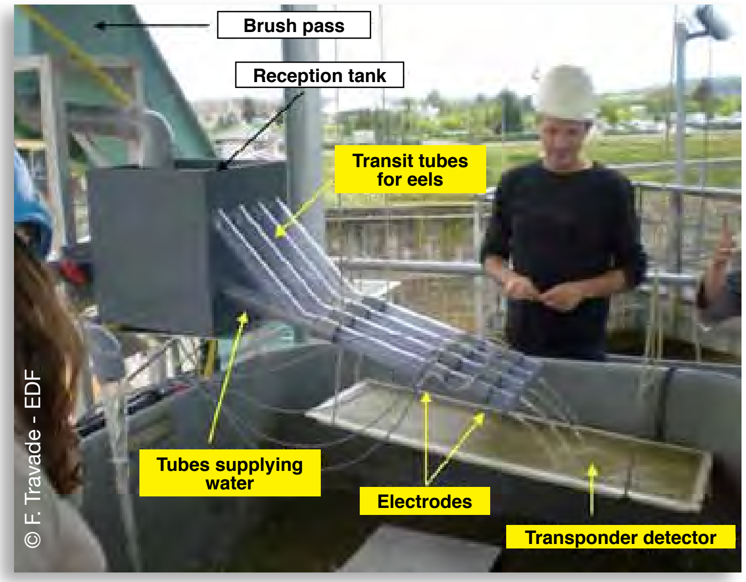
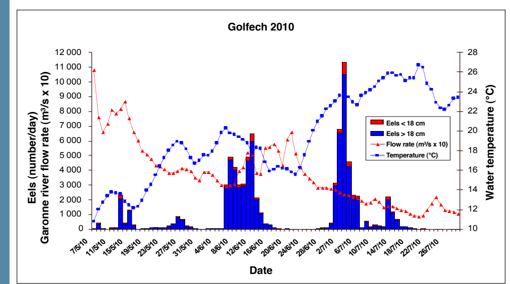


Figure 8. Annual results obtained using the ELTA counter on the fish pass at the Golfech hydroelectric plant in 2010.



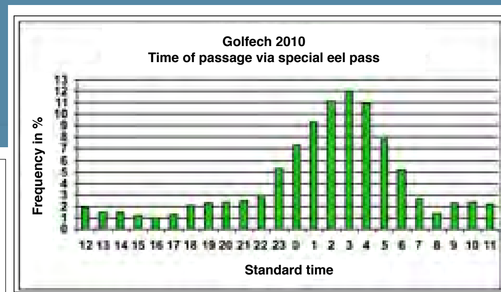


Figure 9. Hourly results obtained using the ELTA counter on the fish pass at the Golfech hydroelectric plant in 2010.

The counter requires electrical power (220 Volts) and frequent monitoring (two to three times weekly) to check a number of parameters, e.g. the flow rate in the tubes and the quality of the data recorded. One to two days are required at the end of each migratory season to validate and sort the data. On major migratory sites (daily peaks above 5 000 fish), a micro-computer must be added to the system for data storage.

Technically speaking, the counter is extremely reliable (compared to manual counting) with a detection rate higher than 99% for several thousand passages. Detection is partial (10 to 90%) for lengths from 125 to 160 millimetres and total for fish above 160 mm. Biometrical results (size and weight of the fish) derived from the signal recorded by the counter are very satisfactory for statistical analysis of an entire migratory population. However, the data are insufficiently precise to accurately measure very small groups of fish.

On the whole, the main drawback to the counter lies in its inability to detect small eels. It is therefore necessary to correct the count data by carrying out regular biometrical measurements in order to calculate the non-detected part of the population. Eliminating this particular drawback could be a topic for further work on this type of counter system.

1.4 Une démarche de priorisation dans la reconquête des axes migratoires

This first chapter presented a panorama of the methods and solutions tested during the R&D programme to improve the passage of juvenile eels through installations during their upstream migration from the tidal zone to the dams located upstream. Implementation of the various systems, tested and validated *in situ* by the programme partners, must now be organised by the widest possible set of stakeholders to encourage colonisation of the freshwater habitats most favourable for the development of the eel stock. River basins are the relevant scale in preparing colonisation. Estuaries are the unique entry point for all eels that will subsequently settle upstream and must constitute the starting point for all future strategies. A number of general remarks (Christian Rigaud, Irstea) based on these conclusions were made during the feedback symposium in November 2011.

In the tidal zone, the installations influencing the migration of glass eels to inland waters and their colonisation are, as noted above, highly diverse in nature (gates, flaps, locks, etc.), in their location (in upstream and downstream sections of estuaries, farther upstream on main river sections or tributaries) and they impact territories of varying size and type. Given this great diversity, any planned work and particularly its location must be based on a prior, precise listing of all the installations in a given river basin. The inventory must indicate for each installation the general upstream context, the presence or absence of glass eels and the potential capacity of the initial upstream reach.

Setting priorities for work is indispensable and will lead to selecting work primarily on the main river in a basin with significant flow rates in the spring and on tributaries where favourable habitats are located. On major river sections in tidal zones, it is advised to set up systems to admit sea water during the winter and spring. Farther upstream, fish passes are recommended for dams. In tributaries and depending on the value of the habitats upstream, admissions are advised taking into account local constraints in terms of acceptable salinity and flow rates upstream. In all cases, the difficulty in foreseeing the arrival of glass eels downstream of installations is an argument in favour of regular admissions during the migration window. This solution has advantages for other species as well and contributes to more stable operation of the zones near the installation. Similarly, progressive and moderate releases during low tides is preferable in order to limit the numbers of fish carried back downstream.

Further upstream, beyond the tidal zone, dams often require solutions designed specifically for eels whose size, during the upstream migration, is generally less than 30 cm. The clear choice is for ramps equipped with mixed substrate sizes and low flow rates. The effectiveness of passes depends heavily on ensuring, with respect to the main flow over or through the dam, both correct positioning of the pass and a sufficient flow to attract the fish. It should not be forgotten that efforts to restore eel stocks, i.e. increase their numbers, will most probably result in a significant reduction in the size of the fish migrating in main rivers or secondary rivers and streams. This phenomena must be taken into account in designing a fish pass, for example using substrates suitable for a wide range of fish sizes.

Given the diversity of situations, the number of partners already involved, the need to share information on methods and results, and to expand the array of situations studied, the research teams in the R&D programme call for the establishment of a national network addressing the topic of upstream migration.

in individual installations

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At the end of the upstream-migration phase, the yellow eels settle in highly diverse freshwater environments. Eels are active generally at night and their subsequent growth takes place entirely in the freshwater environment (7 to 10 cm per year in estuaries and transitional or coastal zones, 3 to 4 cm/year in rivers of moderate quality and 1 to 2 cm/year in rivers offering limited growth potential). The males, more often found in downstream and coastal zones, spend 8 to 14 years in the freshwater environment, the females, more frequent in the upstream areas, remain 10 to 18 years.

It is there that they finally undergo their second metamorphosis and become silver eels at a size of 27 to 50 cm for the males and 45 to 120 cm for the females. They are then ready to set off on the long journey that will take them back to their birthplace, the Sargasso sea, for spawning.

Their trip back to the estuary constitutes the downstream migration. The silver eels take advantage of the autumn flow pulses to join the migrators that grow steadily in numbers the closer they come to the mouth of the river.

During the downstream migration, similar to the upstream, the installations along rivers can have an effect on the movement of the fish and cause mortalities, particularly if the eels pass through the hydroelectric turbines. This second chapter presents the progress made during the R&D programme in understanding and reducing the effects of individual installations. It discusses the new knowledge acquired on the behaviour of migrating eels at installations and the results achieved in quantifying the injuries and deaths caused by transiting various types of turbine. Finally, it looks at the solutions available to limit mortalities, i.e. the development of fish-friendly turbines and water intakes.

2.1 – Eel behaviour when confronted with an installation

On arriving at a hydroelectric plant, a silver eel often has a number of options to overcome the obstacle. In addition to passing through the turbines, it can transit via the spillway, via bypasses for fish if they exist and, occasionally, via the passes intended for upstream migration.

To quantify the damage caused to eels by hydroelectric installations, it is first necessary to determine the proportion of fish travelling via each of these channels. The proportion depends on the characteristics and design of each installation, but also on a number of environmental parameters at the time of passage, i.e. hydrometry, turbidity, water conductivity and temperature.

This analysis (Frédérique Bau, Irstea, Michel Larinier, Onema, Philippe Baran, Onema, François Travade, EDF R&D) was carried out during the R&D programme on a series of six hydroelectric plants (turbine flows ranging from 20 to 110 m^3/s) along a 60-kilometre section of the Gave de Pau river between Jurançon and Puyoo. From 2007 to 2010, a group of 192 eels were tracked using a radio-monitoring technique from November to April. Sets of receiving antennas installed along the river next to each hydroelectric installation precisely determined the channels travelled by the fish and their time of passage.

Hydrology and migratory activity

It is obviously not possible to separate an analysis of the channels chosen by eels from the environmental parameters that influence their behaviour. On the Gave de Pau river, the migratory activity of the eels was estimated based on the number of eels passing through an installation per day of monitoring. During the study, a total of 562 passages by the marked eels were detected.

The passages took place over a wide range of flow rates, from 25 m³/s (low-flow rate) to 800 m³/s, and would appear to be determined essentially by changes in the flow rate in that 83% occurred when water levels were rising. Eel activity was thus interrupted by long periods when they remained relatively immobile, often for several days. Passages generally took place during the night with 83% occurring between 17.00 in the afternoon and 8.00 the next morning. The velocity of downstream migration, also heavily influenced by the hydrological factors, was 3 km/hour on average, but with differences between individual fish and river sections.

Generally speaking, passages through dams were spread fairly evenly over the rated daily flows from the IMF (interannual mean flow) up to the last centile (Q99) (figure 10).

Channels travelled by eels through hydroelectric installations

In the six installations studied, a majority of passages (65%) took place via the spillways. The turbines were the second most important channel (32%), with the other possibilities (bypasses and fish passes) representing only 3% of passages. These averaged values mask significant discrepancies between installations. For example, the percentage of eels transiting the turbines ranged from 2 to 62% (figure 11).

These discrepancies may be explained primarily by differences in the turbine flow rates, in the design of the water intakes and the spillways, in the spacing between the bars of the water-intake screens and by the position of the installation with respect to the point where the eels were released.

A decisive criterion in determining passage channels is of course the relative flow rates in the water intakes (to the turbines) and the spillways. The greater the amount of water flowing via the spillway, the higher the percentage of eels travelling

Figure 10. Cumulative passages as a function of the flow rate for six hydroelectric plants on the Gave de Pau river, with selected rated flows.

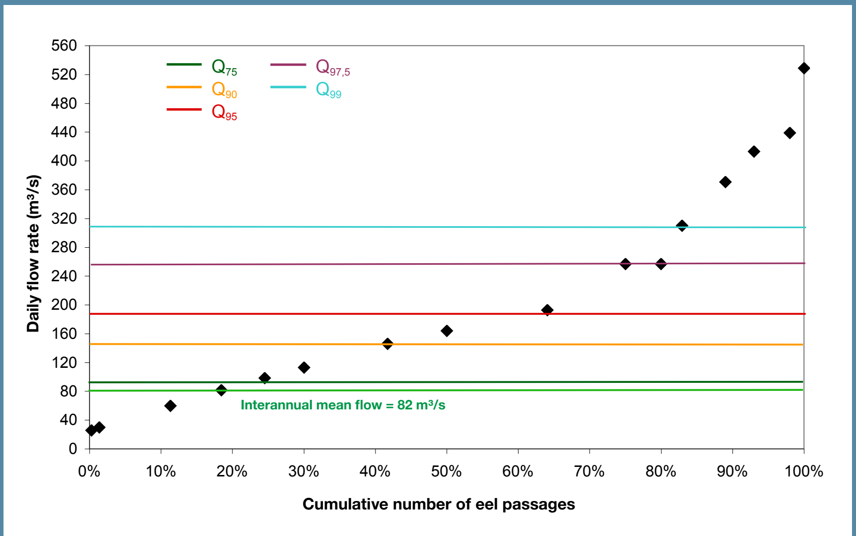
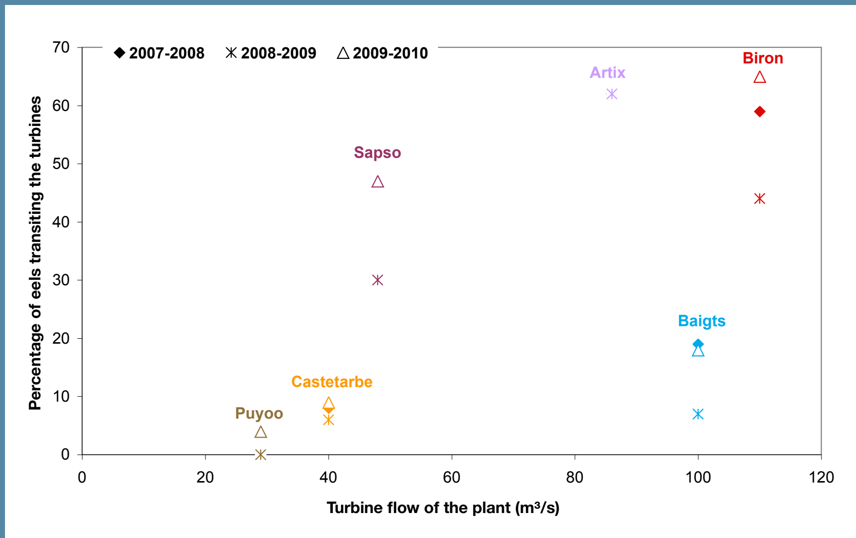


Figure 11. Percentage of eels transiting the turbines as a function of the turbine flows in each installation.

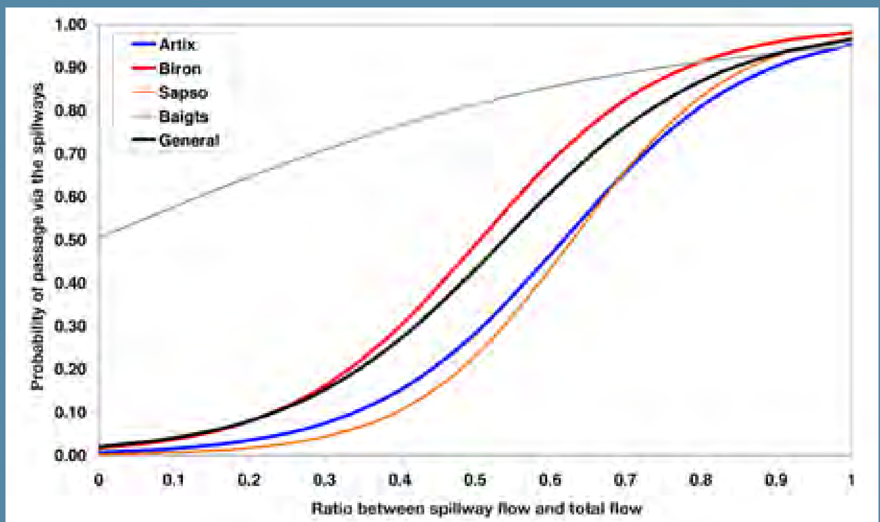


via the spillway. Statistical processing with a general linear model (GLM) was used to produce methods to predict the channel taken by the eels. These models indicate for a given installation (figure 12) the probability of passage via the turbines as a function of the hydrological conditions and notably the ratio between the spillway flow and the total river flow.

The significant differences between installations (figure 12) are due to their specific characteristics. For example, the highly inclined weir at Sapso draws the fish toward the turbines, whereas the plant at Baigts is equipped with screens having small spaces between the bars that reduce the passage of large eels through the turbines.

During a study prior to the R&D programme, a series of experiments were run at the Baigts plant to compare the effectiveness of different arrangements. In 2004, a bypass at the water surface was tested with mid-sized eels, small enough to pass

Figure 12. Model of the probability of passage via the spillway as a function of the ratio between the spillway flow and the total river flow.



through the screen. In 2005, a bottom bypass was tested and, in 2006, a screen with small spaces between the bars was tested with a surface bypass and large eels. In the first two cases, a large percentage (60% and 54% respectively) of the eels went through the turbines.

The third configuration, however, limited passages through the turbines to 8%. Observations revealed that when a screen with small spaces was installed, the eels waited just upstream for a flow pulse to pass the obstacle via the spillways. No deaths due to impingement on the screens were noted for flow speeds ranging from 10 to 40 cm per second. These observations confirm the effectiveness of screens with small spacing. They also argue in favour of using the surface bypasses for salmon during the downstream-migration period of eels.

Generally speaking, the study on the six plants along the Gave de Pau river produced new knowledge on the behaviour of silver eels upstream of hydroelectric installations. It confirmed the importance of the specificities of each plant and revealed the high percentages of passages via the spillways. Finally, tools were developed to estimate escapement rates as a function of hydrological conditions and relative flow rates at the water intakes. These data will be of great use in evaluating the cumulative harm caused by hydroelectric turbines along entire river sections, a topic discussed in the third chapter.

A similar approach, again in the R&D programme, was implemented on the French part of the Rhine to see how eels overcame a series of obstacles (E. de Oliveira, EDF-LNHE). This project called on the NEDAP technology using RFID (radio-frequency identification) to detect eels equipped with subcutaneous chips when they passed six stations outfitted with long-range antennas suited to large rivers such as the Rhine. During the first two years, the experiments suffered from numerous technical problems that have since been solved. Though expensive and difficult to implement, this technique, in conjunction with the mortality equations for turbines, should inform on the numbers of eels migrating downstream and succeeding in passing the installations along the French section of the Rhine, as well as the time taken by each individual, which can vary considerably. For this project, the plan is to equip and release over 300 eels each year over the next four or five years.

2.2 – Impact of turbines on eels migrating downstream

To determine mortality rates inflicted by an installation on eels migrating downstream, it is necessary to know the percentage of the fish transiting the turbines (the topic of the previous section) and the percentage of transiting eels that are effectively killed by the turbines. The latter obviously depends on the type of turbine installed. The development of models to predict mortality rates depended on the availability of experimental results, of which there were very few at the start of the R&D programme.

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Experiments on large turbines

An *in situ* project (Éric de Oliveira, EDF-LNHE, Franck Pressiat, CNR) was carried out in 2009 and 2010 to determine mortality rates caused by large Kaplan and Bulb turbines, used extensively in France and particularly in the Rhine and Rhône rivers.

The tests were carried out on two Kaplan turbines (4 and 5 blades) on the Rhine river, in 2009 and 2010 by EDF, and on a Bulb turbine on the Rhône, in 2010 by CNR. In each case, the Hi-Z tagging technique was used, i.e. inflatable balloons that make it possible to capture the fish downstream of the installation. A minimum of 350 large eels (60 to 90 cm) were used for each test, i.e. 300 were injected at three different points into the turbines and a control group of 50 were injected downstream. The

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recaptured fish were then examined and subsequently put into a holding tank for 48 hours to check for any delayed mortalities.

Study results were reinforced by high recapture rates (over 95% on each of the three sites) and very high survival rates among the control groups, which enhanced the robustness of the survival and injury rates presented in table 2.

At Fessenheim and Beaucaire, the injury rates were lower than expected given similar tests carried out on other sites (U.S., Canada, Netherlands). On the other hand, the rates at Ottmarsheim (5 blades) were significantly higher. An explanation of these differences will require further work. The particular shape and profile of the runner and blades may be responsible for the high injury rates. Meetings with the turbine manufacturer and EDF have been arranged to analyse the matter further.

Predictive models for Kaplan turbines

The cost and difficulty in running this type of *in situ* project means that similar operations are not possible for each and every type of turbine installed on rivers in France. The potential damage caused by a turbine can nonetheless be roughly

Table 2. Mortality rates in large turbines (E. de Oliveira, EDF R&D, F. Pressiat, CNR).

Plant	Characteristics of turbines and installations			Survival rate		Injury rate	Percentage of uninjured individuals
	Diameter	RPM	Head	1 hour	48 hour		
Fessenheim Kaplan 4 blades	6.67 m	88.2	15.7 m	93.2 %	92.4 %	7.4 %	92.6 %
Ottmarsheim Kaplan 5 blades	6.25 m	93.7	15.5 m	82.6 %	78.6 %	27.6 %	72.5 %
Baucaire	6.24 m	94	16 m	95.6 %	92.3%	8.4 %	91.6 %

estimated by extrapolating the results of tests on similar turbines or by using predictive models developed using the experimental results obtained on other sites.

This project (Peggy Gomes, Onema, Michel Larinier, Onema), a part of the R&D programme, addressed Kaplan turbines (excluding very large units) that equip a large number of low-head installations in France. This work used the data from experiments carried out on 24 sites in Europe and North America. A total of 71 tests on 15 sites contained the necessary information on mortality rates, turbine physical characteristics and operating conditions during the tests. Analysis and statistical processing were used to develop predictive models (see Gomes and Larinier, 2008).

The experiments revealed highly variable mortality

rates depending on the sites and on the types of turbine. Generally speaking, injury and mortality rates increased with the size of the eels and the rotational speed of the turbines, and decreased for smaller turbine diameters and lower nominal flow rates. Mortality rates ranged from 5% to 10% for large, low-head turbines and exceeded 80% for certain small Kaplan turbines with high rotational speeds.

Three mathematical models were developed on the basis of tests carried out with flow rates higher than 70% of turbine flow and using exclusively data that were easily accessible. The models provide a rough estimate of mortality rates (M) as a function of eel size (TL), the diameter of the runner (Dr), the nominal flow rate (Q) and the rotational speed of the turbine (N). The consistency in the results of the three models was confirmed by running tests on approximately 60 Kaplan turbines. Use of the models depends on the availability of the data for the evaluated hydroelectric installations.

The absence of the number of blades and the head in the predictive models is due to the limited number of tests and above all to the lack of data for certain Kaplan designs. A majority of the tested turbines had four blades, very few had three, five or more blades. Turbines rated less than 500 kW operating with very low heads (less than 3 to 4 metres) and large turbines rated 10 to 50 MW with nominal flow rates higher than 150 m^3/s and heads between 10 and 20 metres were also under-represented in the collected documentation. This work will be filled out and improved by adding the results of the *in situ* experiments on the Rhine and Rhône rivers presented above.

The models are nonetheless operational and may be used once the data on the turbine characteristics have been validated. For a given site, the models can estimate the mortality of that part of the silver-eel stock transiting the turbines.

2.3 – Fish-friendly turbines

One solution to reduce the impact of hydroelectric plants on eels is to use «fish-friendly» turbines designed to reduce or eliminate the factors injuring the fish, i.e. blade strikes, becoming stuck between the blades and the housing, flow shear, velocity and pressure gradients.

An example is the VLH (Very low head) turbogenerator developed by the MJ2 Technologies company. The initial prototype of the low-head turbine was installed in Millau and put through downstream-migration tests using smolts and silver eels in 2008. The tests confirmed the fish-friendly characteristics of the VLH turbine and paved the way for a number of improvements that have since been made, i.e. modifications to the blade profile and a new spherical runner housing to reduce the clearance at the end of the blades at all openings.

For the R&D programme, the new version of the VLH turbine was tested *in situ* at Frouard on the Moselle river. The turbine, 4.5 metres in diameter with eight blades and a maximum output of 400 kW, had been in operation since February 2010. For the tests run by MJ2 Technologies and Ecogea, 244 large eels (70 cm median size) were caught in the Rhine and injected at four points in the turbine via a plastic tube attached to the wicket gate. The turbine operated at full-rated flow and power output during the test. The fish were recovered downstream in a polyamide net under a floating platform.

The results confirmed the excellent fish-friendly characteristics of the system. The percentage of lethal injuries was zero and that of minor, non-lethal injuries within 24 to 48 hours was approximately 2%.

The Alden turbine, a promising solution for high heads

The R&D programme (F. Travade, EDF R&D) also contributed to the industrialisation procedure for the ALDEN fish-friendly turbine, under development since 1995 in the U.S. with support from the Department of Energy. The turbine, constructed by Voith Hydro, is equipped with three helicoidal blades and designed for high heads from 6 to 37 metres.

Following the design of the runner using digital modelling techniques, biological tests were carried out at the Alden hydraulics laboratory on a 1:3.25 scale prototype. Approximately 40 000 fish (six species), ranging in size from 36 to 425 mm, were sent through the turbine. The survival rate of the fish, extrapolated to a full-scale turbine, was calculated at between 97 and 100%. For eels between 250 and 430 mm, the survival rate in the model turbine was 100%. However, extrapolation of the results to eels representative of the stock migrating downstream (600 to 1 000 mm) was considered too uncertain.

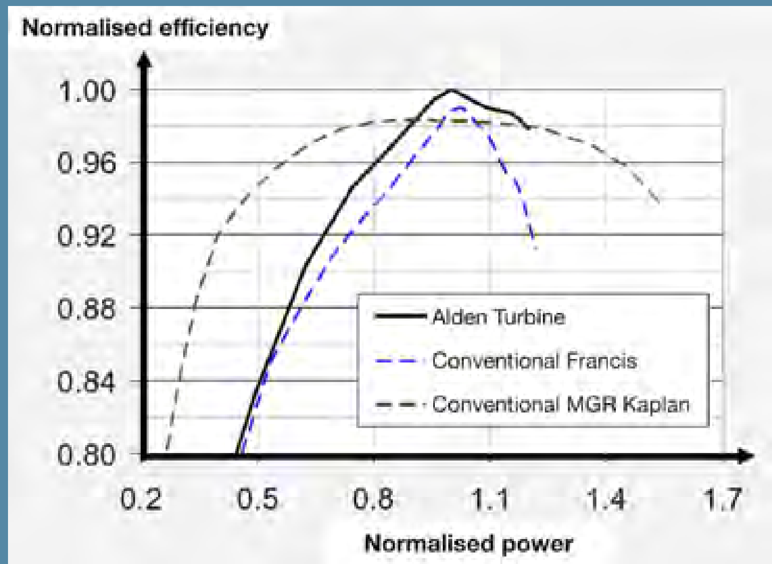
Following the satisfactory biological tests, the final design work was carried out by Voith Hydro from 2008 to 2010 with a triple goal, i.e. optimise turbine efficiency, maintain the fish-friendly characteristics and reduce manufacturing costs. The digital modelling and the tests on the physical model (1:8.7 scale) then shifted to the industrial-design phase which produced a turbine with optimised characteristics, namely a runner diameter of 3.7 metres, a flow rate of 45 m^3/s, a head of 28 metres, 120 rpm and a rated power output of 11 MW.

The rated efficiency is 93.6%, a result equivalent to conventional turbines. The Alden turbine is in fact more efficient than the Francis turbine, but has a more narrow implementation range than the Kaplan turbine (figure 13).

Biological tests run *in situ* have been programmed by EPRI on a turbine similar in size to the one optimised by Voith Hydro. The tests will consist of measuring survival rates for various species and lengths of fish sent through the turbine.

The effectiveness of the Alden turbine for eels will not be confirmed until 2015, following the *in situ* biological tests carried out on fish representative of the stock migrating downstream (600 to 1 000 mm long).

Figure 13. Comparative performance levels of Alden, Francis and Kaplan turbines.



The main limit to deployment of the Alden turbine is that its diameter is greater than that of other turbines with equivalent head and flow characteristics. That means it will not be possible to renovate existing installations with Alden turbines without major structural changes. Consequently, the Alden turbine would appear to be best suited to new developments, added capacity at existing dams, minimum-flow releases and other bypass systems. Its use is theoretically possible for heads between 6 and 37 metres and for flow rates between 14 and 57 m^3/s. Mortality rates for eels given the above head and flow characteristics must be determined by *in situ* tests.

The VLH and Alden turbines, which function under very different operational conditions, would appear to be good alternatives to existing systems in view of reducing mortality rates inflicted on fish migrating downstream by hydroelectric plants. However, considerable development work remains to be done in order to propose fish-friendly turbines for heads in the intermediate range.

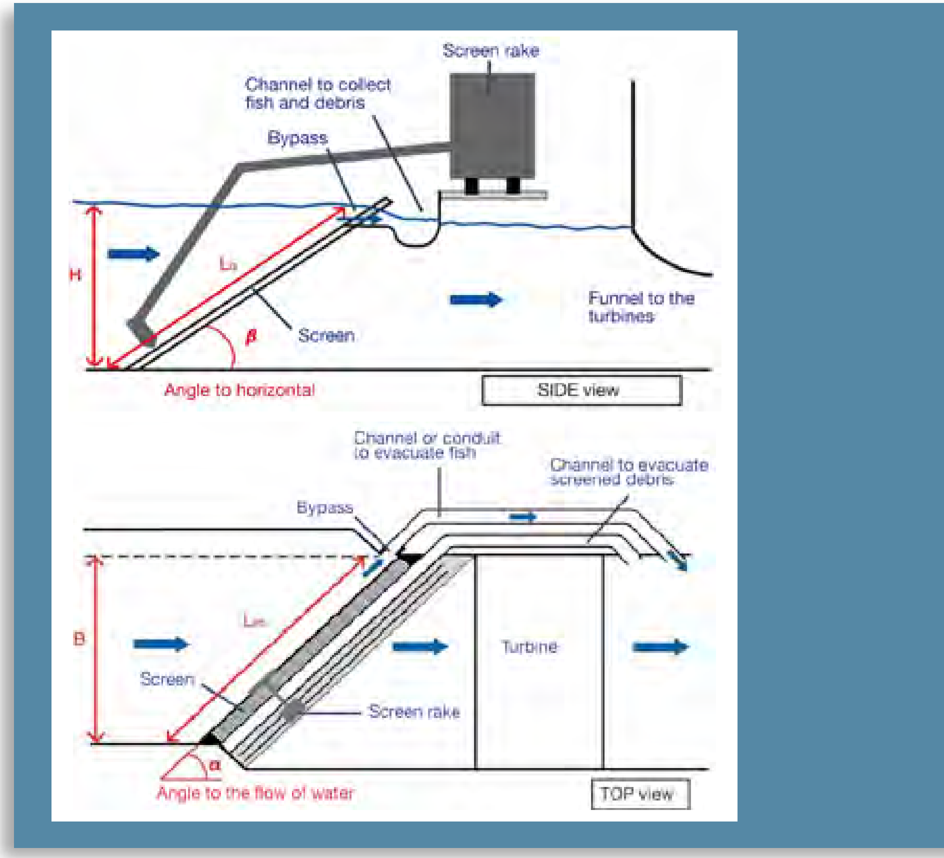
2.4 – Fish-friendly water intakes

In addition to the work on developing low-mortality turbines, the R&D programme also looked at solutions to block the access of eels to the turbine water intakes. An infrasonic repulsion device developed by Profish Technologies was tested for two years, with 150 eels equipped with emitters, on two sites on the Gave de Pau river with very different layouts. The system failed the test (F. Bau, Irstea) because no significant differences were noted in the behaviour of the eels when the system was in operation. In the absence of effective repulsive systems, the best means to stop eels from transiting turbines remains screens with small spaces between the bars in conjunction with one or more bypasses to ensure passage downstream without harm.

In 2008, a study (Courret and Larinier) established the basic parameters for the design and sizing of screens, based on feedback from experiments carried out in France and abroad. To guide the fish toward a bypass, it is advised to install either:

- screens set perpendicular to the flow and inclined at a low angle from the bottom, with one or more bypasses, depending on the width of the intake, positioned at the top;
- or a vertical screen set at an angle to the flow, with the bypass at the downstream end (figure 14).

Figure 14. Simplified diagram of «fish friendly» water intakes, inclined (upper diagram) and angled (lower diagram). (Courret and Larinier, 2008)



It is also advised to use screens with 1.5 to 2 cm spaces between the bars, while limiting the normal velocity perpendicular to the screen face to a maximum of 50 cm/s in order not to impinge the fish.

These design criteria for fish-friendly water intakes imply major changes with respect to standard installation designs as well as consequences in terms of head losses caused by the screens (and consequently installation efficiency) and screen maintenance (raking). In the R&D programme, a project (Laurent David, Institut P', Ludovic Chatellier, Institut P', Dominique Courret, Onema, Michel Larinier, Onema) pursued the design work on fish-friendly water intakes in view of producing an operational solution with a triple goal:
- determine the head losses incurred by screens with narrow spaces between bars in fish-friendly configurations (inclined or angled) in order to validate or adapt existing equations, or propose new equations if necessary;
- determine approach velocities to the fish-friendly screens in order to check whether the recommended design criteria produce the desired hydraulic conditions for fish migrating downstream and, if necessary, improve the design criteria;
- determine the position and flow criteria for bypasses in each configuration.

Work continues on the third goal. The study consisted of an experiment using a physical, scale model, first in a basin with the screen pulled through a channel, then in a hydraulic channel, custom-made for the project, at the Institut P' site in Poitiers, France. The screens were built to half scale. A total of 88 configurations were tested, combining eleven screen positions, i.e. inclined and angled screens, four sizes of spaces between the bars ranging from 10 to 30 mm and two bar shapes (rectangular PR and hydrodynamic PH). The influence of partial screen clogging on head losses and flow velocities was also studied by adding perforated plates. Head losses were determined by measuring the differences in water levels upstream and downstream of the screen. Flow velocities were calculated using velocity profiles along the screen face acquired by an ADV (acoustic doppler velocimetry) device and laser measurements.

The experimental results for head losses showed that the head-loss equation developed by Meusburger (2002), the most complete to date in the scientific literature, is not suitable for fish-friendly screen configurations. Two new

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equations for head losses, for angled and inclined screens respectively, were developed and are shown in the box below.

The study also precisely determined the velocity profiles along the screens, thus making it possible to calculate the approach velocities required to avoid impinging the fish on the screens and to provide optimum guidance toward the bypass. Concerning guidance, it is advised to install screens at an angle of $\beta \leq 26°$ (inclined screens) or $\alpha \leq 45°$ (angled screens).

An additional study is now underway at Institut P', in the framework of a partnership between Onema and the hydroelectric companies (SHEM, CNR, EDF, FHE), to determine positioning and flow-rate criteria for bypasses in each configuration. The final presentation of project results is planned for the first half of 2013. The results of all these studies will enable the State services and the industrial companies to better understand the technical modifications required in installations to help in saving the eel.

Head-loss equations

Head-loss equation for vertical screens set at an angle to the direction of flow

$$\Delta H = \frac{V^2}{2g} * \left[A * \left(\frac{O}{1-O}\right)^{1.6} * \left(1+C * \left(\frac{90-\alpha}{90}\right)^{2.35} * \left(\frac{1-O}{O}\right)^{3}\right)\right]$$

Where V is the upstream flow velocity, A and C are the bar-shape coefficients representing 2,89 and 1,69 for PR and 1,70 and 2,78 for PH respectively. This equation is valid for vertical screens ($\beta = 90°$) set at an angle α to the direction of flow of 30° to 90°, and applicable for blockage ratios O from 0.35 to 0.6, for bar thickness to bar depth ratios b / p in the vicinity of 0.125 and for bar spacing to bar thickness ratios e / b between 1 and 3.

Head-loss equation for inclined screens (angle from the bottom)

$$\Delta H = \frac{V^2}{2g} * \left[A * \left(\frac{Ob}{1-Ob}\right)^{1.65} * \sin^2(\beta) + C * \left(\frac{Oent}{1-Oent}\right)^{0.77} \right]$$

Where V is the upstream flow velocity, A is the bar-shape coefficient representing 3.85 for PR and 2.10 for PH, and C is the shape coefficient for spacers and other transversal elements, which may be considered a drag coefficient (1.79 for cylindrical spacers). This equation is valid for screens set perpendicular to the flow ($\alpha = 90°$) and inclined at an angle β from the bottom of 15° to 90°, and applicable for overall blockage ratios O from 0.35 to 0.6.


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along entire river sections

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The scientific results presented in the previous chapter represent significant progress in understanding the effects of individual installations on eels migrating downstream. Other factors, notably fish-friendly turbines and water intakes, studied in the R&D programme are also operational solutions available to limit the impact of individual installations.

Decisions concerning implementation of these results must, of course, be based on an overall analysis. The cumulative escapement rate for a series of installations, i.e. the total percentage of migrating eels reaching the estuary of a river basin, must be analysed on the scale of entire river sections. Integrated analysis is required to set priorities, select and implement the work required locally to reach the goals set by the eel-management plan. It is also on the river-basin scale that precise halts in generation during migratory peaks can be planned and evaluated in economic terms.

These overall approaches are essential factors in local policies and the topic of this third chapter.

3.1 – A promising method to determine cumulative impacts

The progress made in the R&D programme in evaluating the impact of each installation (behaviour of eels approaching an installation, percentage of eels transiting the turbines, mortality rates caused by different types of turbines) paved the way to quantifying the impact on eel populations along entire river sections. Quantification depends on in-depth knowledge of migratory activity in the river and a detailed inventory of the installations present including their respective configurations.

To that end, a project (Peggy Gomes, Onema, Michel Larinier, Onema, Philippe Baran, Onema) in the R&D programme developed and applied to real situations a method designed to evaluate survival rates over entire river sections.

The method, designed to diagnose situations and set work priorities, is based on integrating three models.

- A model to estimate daily numbers of silver eels arriving at hydroelectric installations. This ambitious project integrated a number of environmental parameters (weather, hydrology, turbidity, etc.) and was tested on the Loire river. It is presented in section 3.2. below. For the integrated method presented here, however, a different approach was preferred, i.e. one linking the migratory activity of eels to the range of characteristic flow rates, based on the data obtained on the 562 passages of eels through installations on the Gave de Pau river. The results (figure 10, section 2.1.) revealed a fairly equal distribution among the rated flows Q_{75}, Q_{90}, Q_{95}, $Q_{97.5}$ and Q_{99}. This hydrological data has the advantage of being more available for large-scale projects than the experimental parameters listed above.

- A model to determine eel distribution between the turbine intakes and the other channels of hydroelectric installations. This model is the result of statistical processing (GLM) of 476 passages on the Gave de Pau river as a function of the ratio between the spillway flow and the total river flow (figure 12, section 2.1.). The probability of passage via the turbines as a function of this ratio depends, of course, on the configuration of the given installation and the turbine flow. Each type of installation therefore requires its own model. On the whole, installations with weirs inclined in the direction of the flow would appear to be the worst for eels. Among installations built perpendicularly to the flow of water, the proportion of eels transiting the turbines increases with the size of the water intakes.

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- Finally, a model to **estimate the potential mortality of the eels transiting the turbines**. It is based on predictive equations developed using the bibliographical work and analyses presented in section 2.2. The data from the 29 tests drawn from the scientific and technical literature served to formulate links between mortality rates as a function of eel size and certain turbine characteristics (diameter, rotational speed and nominal flow rate).

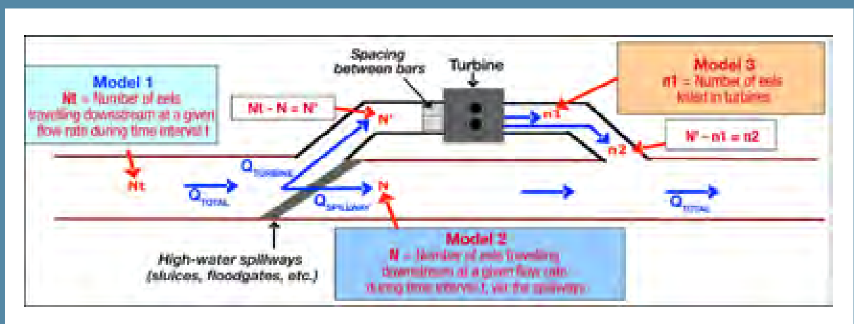
Integration of the three models (figure 15) produced estimates on the damage inflicted by a given installation.

Implementation method and initial results

The research teams in the R&D programme proposed an implementation method for the new tool. The first step was to collect the necessary data on river hydrology, installation characteristics and the eel populations in the river basin.

The hydrological data were drawn from the Banque Hydro database, using the daily flow rates during the downstream-migration period of eels (this period depends on local conditions). The data must be recalculated

Figure 15. Cumulative losses for a series of installations by combining predictive models for single installations.



for each installation taking into account the percentage of the river basin draining to that installation. For each year that the data were available, characteristic values of the rated flows were calculated.

The information on each hydroelectric installation must be collected from the various State agencies and then filled out and validated with survey data obtained directly from the installation management. Finally, data on eel stocks in rivers and the distribution of silver eels must be calculated on the basis of either the surface area of the river basin or the length of the river.

This data-collection phase may require 15 to 30 days of work for river sections with 15 to 25 installations.

The overall method must first be run on a single installation. For each annual value of the rated flows, the migrating eels assigned to a given size (model 1 in figure 15) were distributed between the turbines and the spillways (model 2). The eels transiting the turbines were assigned a mortality rate (model 3). To estimate the overall escapement rate for an entire river section, the rates for each installation were calculated successively. The eels arriving upstream of installation N comprise those that succeeded in passing installation N-1 and any eels arriving from habitats located in the river section between the two installations.

This calculation phase may require 5 days of work for river sections with 15 to 25 installations.

This method, the only validated method to date, estimates for a given year and period the percentage of eels surviving each installation and an overall percentage of eels surviving the cumulative impact of all the hydroelectric installations. For the R&D programme, it was applied to a river in Southwest France comprising 26 installations, assuming a uniform distribution of the eels based on the size of the overall river basin. The model indicated an overall percentage of escaping eels between 33% and 66% depending on the year, with an average of 49%. The differences between years may be attributed to varying hydrological conditions.

This information is most useful in diagnosing entire rivers, in comparing the relative impact of installations and in setting priorities for work to enhance the survival rates of eels. However, the current model is based on monitoring data of eels migrating downstream drawn exclusively from the Gave de Pau river, which is of the pluvio-nival type. In other types of rivers, the favourable periods and flow characteristics for downstream migration are likely to be different. To ensure optimum model implementation, it is advised to use all local data available on eel downstream-migration rhythms as much as possible.

3.2 – Anticipating downstream-migration periods for better turbine management

Above and beyond a diagnosis on the cumulative impact of installations, the work on the river-basin scale serves to determine the technical and economic conditions for precise halts in generation during migratory peaks. This solution, in addition to the modifications in installations already mentioned, would appear to be an effective means to reach the national objectives for eel restocking. However, its implementation must take into account the economic and social issues involved in hydroelectric generation. Acceptable shutdown durations must be determined through negotiation with each operator and for each installation. In all cases, shutdowns must ensure the best possible escapement rates for silver eels. It is with this in mind that the capacity to predict peaks in migratory activity must be seen as a crucial factor.

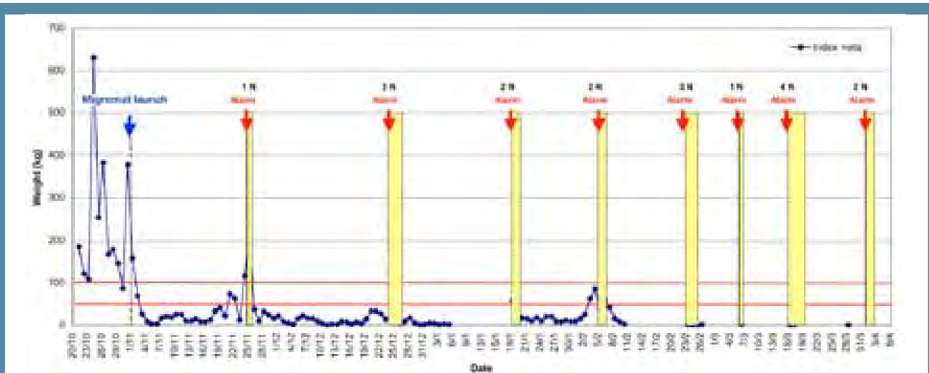
Late alarms by Migromat®

Information on downstream-migration rhythms was produced by the monitoring projects in the six stations on the Gave de Pau river and presented in section 2.1. But other approaches were also initiated by the teams working in the R&D programme. For example, tests were run in Ireland (Kieran McCarthy, Ruairi MacNamara, Ryan Institute and School of Natural Sciences, Michel Larinier, Onema, François Travade, EDF R&D) on River Shannon to assess the Migromat® biomonitor. The system is based on the fact that silver eels held captive in basins supplied with water from the river show signs of enhanced activity during peaks in downstream migration. The system was installed from September 2008 to March 2010 in Killaloe, upstream of a fishery using 34 nets for a capture and transport operation, including eight index nets pulled up daily. Approximately 30 eels were held in two tanks (5 cubic metres each) and equipped with transponders to monitor in real time their activity using a computer program. When the signals were deemed characteristic of a peak in migration, an alarm message was sent by e-mail.

The test consisted of comparing the alarms generated by the biomonitor to the peaks in migratory activity registered by the fishery and of calculating the percentage of the migratory stock that would have survived had the turbines been shut down overnight (18.00 - 7.00) during the alarm period. During the two migratory seasons, the test was carried out for continuous periods of at least 60 days.

The results were mediocre. Depending on the calculation method, Migromat® would have enabled 14 to 29% of the eels migrating downstream to escape if it had been used to trigger turbine shutdowns. Those rates are well under the escapement goals set by the eel-management plans which target a reduction of 75% of all causes of mortality. The limited effectiveness of the system was due essentially to the fact that detection occurred fairly late during the peak in migratory activity. Alarms were issued during the migratory peaks (figure 16), but only once each peak was well underway and occasionally several days after the start of the peak. Given the results to date, Onema has concluded that the Migromat® system may not be certified by the regulatory authorities in France to serve as the basis for a turbine-management system. On the whole, the opinions of professional fishermen proved better in predicting the downstream migration of eels.

Figure 16. Captures at Killaloe and alarms - Migromat® 2008-2009



Experimental fishing campaigns for valuable information

Another experiment (Laurence Lissalde Bonnet, EDF CIH), requiring more resources but producing better results, was run on the Dordogne river to study local eel downstream-migration rhythms. The project took place in the sluice supplying the Mauzac hydroelectric plant. The goal was to determine whether sampling catches were a feasible solution to gain knowledge on the migratory flows of eels and on the influence of environmental parameters such as the flow rate, water temperature, conductivity and turbidity, the lunar phases, etc.

The system, designed with the assistance of professional fishermen, used the same «guideau» net as commercial firms. The net was lowered from a floating platform attached to the banks. The guideau net represented about 10% of the cross-sectional area of the sluice and remained in the water current for several hours. The eels were recovered from the net using a boot to which the extreme downstream end of the net was lifted.

The experimental fishing system worked smoothly during the two monitoring campaigns. A total of 214 eels were caught during 140 nights the first year (from 1 September 2009 to 26 January 2010) and 118 eels were caught during 122 nights the second year (from 8 November 2010 to 13 March 2011). A CMR (capture-mark-recapture) operation was used the first year to estimate the effectiveness of the fishing campaigns. The results came in at 8%, which is close to the size of the net compared to the sluice (10%).

Analysis of the results showed that the selected period (1 September - 31 December) did not include the main peaks in downstream migration which take place later (January and February).

On the whole, the system proved valuable in collecting information on the influence of environmental parameters on downstream migration (essentially the flow rate and turbidity). It represents a useful source of data for local «models» to predict downstream migrations. The initial predictive models on eel presence/absence proposed by the researchers could be tested against the captures of the fishing campaign in 2011.

However, this type of fishing system is probably limited to installation configurations where the flow is narrowed to a smaller cross-sectional area in order to cover a larger percentage of the downstream flow with the net. When the nets are located in the sluice of a hydroelectric plant, discharges via the dam (with escaping eels) must be limited to avoid disturbing the catch results. It should be noted that the low velocities during low-flow periods can render the operation of guideau nets difficult and even impossible.
This type of fishing campaign is expensive (approximately 50 000 euros for the entire installation) and requires considerable resources because a team of at least two people must be on hand every night for twelve hours (18.00 in the evening until 6.00 in the morning) and for at least four months.

A promising approach to modelling downstream migration on the Loire river

An experimental fishing system such as the one presented above is a valuable source of local data on the downstream-migration rhythms of eels that can be linked to environmental parameters. In operational terms, the data paves the way for predictive models capable of reliably signalling peaks in migratory activity in advance. Forewarning of 24 hours would appear to be necessary to provide installation managers the time required to plan turbine shutdowns.

For the R&D programme, this type of model was developed (Anthony Acou, MNHN) for the Loire river between Angers and Nantes. This is the only river section in France for which a long data series on the capture of silver eels is available due to the long-standing presence of a highly organised, professional fisheries association. The goal of the project was to select, on the basis of a bibliographical analysis, the environmental factors likely to determine migration windows and to develop a predictive model for downstream migration based on the number of eels caught per night of fishing.

On examining the fishing records, it was possible to extract a valid series of capture data, essential for model calibration, spanning 20 years (1987-2006) of daily captures using «guideau» nets anchored in the flow. The data were the averaged daily values from four fisheries. A general linear model (GLM) technique was used to develop two models. The first estimates the probability of eel presence/absence and if the fish are effectively there, the second estimates the numbers of eels migrating downstream. The final model predicts eel captures on a given day using an equation (see box).

The model, designed to predict downstream-migration windows 24 hours in advance, is reliable in that 80% of all observed peaks in activity were predicted. It does, however, tend to «over-predict», i.e. announce peaks that subsequently do not occur. Figure 17 compares the predictions with actual captures during the year 1987. Turbine shutdowns were simulated in the study zone. Model results for escapement were compared with turbine-shutdown management based exclusively on flow-rate threshold values. Simulation results came out clearly in favour of the «environmental» model. The latter ensured an eel-escapement rate of 45% with the turbines shut down 19 nights, whereas the hydrological method (shutdown when the flow rate exceeds a threshold value) produced an identical escapement rate, but required 63 nights of turbine shutdown. Note that 120 nights of turbine shutdown would be required to ensure a 100% escapement rate for the eels along this river section.

This research project made significant progress in our capacity to offer installation managers, under certain conditions, better management of turbine shutdowns in the effort to save the eel. The essential next steps, i.e. extrapolation of the model and testing of its predictions in other river basins (currently the Dordogne basin) are now underway. The future results will serve to adjust the model and perhaps generalise its use at some later time. Finally, another study is now in progress on smaller rivers to determine whether a smaller number of environmental parameters (variations in the flow rate, rainfall) would suffice to predict downstream-migration rhythms sufficiently well.

Additional elements for turbine management based on hydrological factors

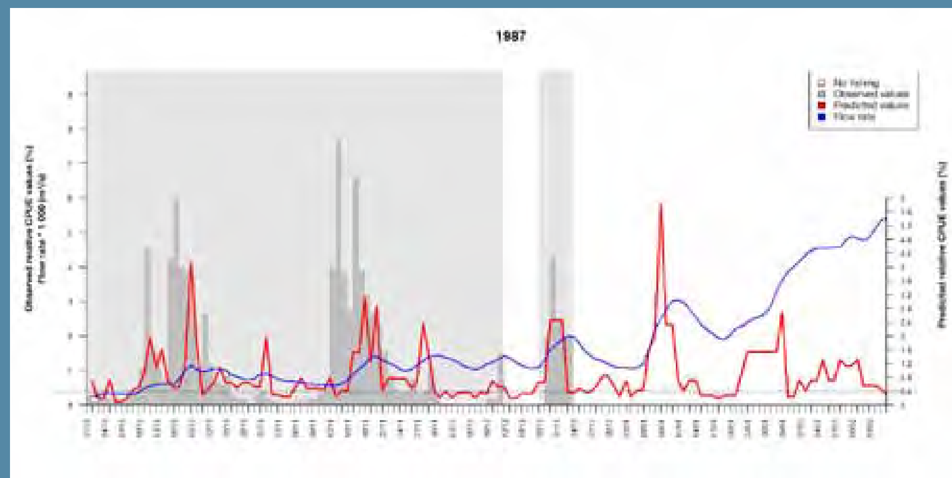
In parallel with the work on modelling daily eel numbers based on environmental factors, quantitative data was produced (Ph. Baran, Onema) for the R&D programme to estimate the potential duration of turbine shutdowns based on

Estimating the daily flows of silver eels

$$CPUE_j = \Delta Q_{j-1} + TURB_{j-1} + IL_j + SEM_j + TEMPS_j$$

This equation brings into play:
- the daily variation in river flow rate (ΔQ, in %);
- turbidity (TURB, in NTU = nephelometric turbidity units), which quantifies the amount of light perceived by an eel in the water column;
- the luminosity index (IL, not expressed in units; Cairns & Hooley, 2002), which quantifies the total nightly light based on the lunar phases and cloud cover. This index varies from 0 (e.g. a new moon with heavy cloud cover) to 1 (full moon with a clear sky all night). Each night, the IL index provides a much better estimate of the light perceived by eels at the water surface than the previous system based solely on the lunar phases;
- the number of the week (SEM);
- the weather situation (TEMPS, Paquet *et al.*, 2006), which describes the atmospheric conditions according to eight general parameters (central low-pressure zone, high-pressure zone, easterly winds, etc.).

Figure 17. Effective numbers of eels caught in the Loire river per night of fishing in 1987 and numbers predicted by the model.

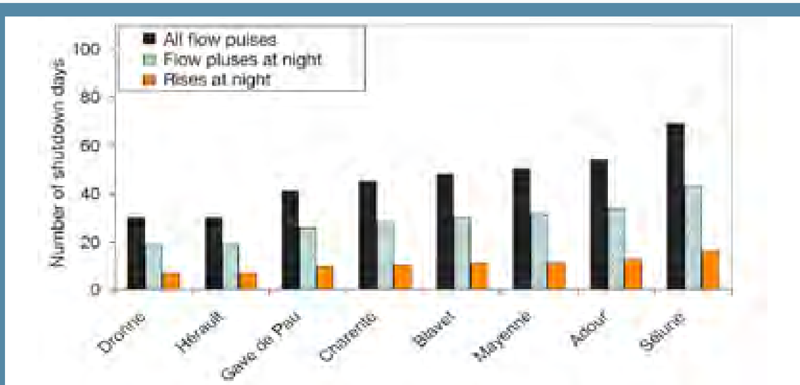


hydrological analysis of rivers during the downstream-migration period.

The monitoring results on the Gave de Pau river (section 2.1.) provide a fairly good idea of the flow conditions linked to windows of downstream migration. For example, 83% of passages through installations take place during «flow pulses», i.e. when flow rates change significantly. In addition, 83% of passages also take place at night (17.00 in the afternoon to 8.00 in the morning) and 50% of passages occur during flow pulses greater than four times the interannual mean flow (IMF). It should be noted that increases in flow starting at night on the Gave de Pau river occur, on average, ten times per year and represent 59% of eel passages. These results cannot, however, be widely generalised given the very specific nature of the experiments on the Gave de Pau.

For other rivers, having different hydrological regimes, shutdown durations to achieve similar passage rates may vary widely. Analysis of the hydrological series for eight other French rivers was used to estimate, as a basis of comparison, the number of times flow pulses occurred, the number of times flow pulses occurred at night and when only the first part of the flow pulse (rise in water level) occurred at night. The results are shown in figure 18.

Figure 18. Potential turbine-shutdown durations for different managements scenarios in eight French rivers.



In any case, one of the main problems in turbine shutdowns is the difficulty in predicting these hydrological events and in planning shutdowns. The best solution remains monitoring the flow gradients upstream in the river basin. However, anticipating flow pulses in this manner depends on the upstream and downstream signals being similar and, once again, situations diverge from one river basin to another. The analysis of five French river basins (Blavet, Charente, Dronne, Gave de Pau, Hérault) showed that the similitude existed for four basins, but not for the Gave de Pau. But even the condition of upstream-downstream similitude is not sufficient. For the four rivers mentioned above, predicting flow pulses would appear possible for the downstream sections, but not for the mid sections. For the Charente and Dronne rivers, 100% could be predicted 24 hours in advance using an upstream reference point, whereas only 50% could be predicted for the Hérault river.

Onema research teams have identified a few generic criteria to detect rivers in which this approach may be used to predict flow pulses. The river basins must be fairly large, have consistent hydrological regimes and the downstream basin surface area must be at least 15 times larger than the upstream reference basin.

That means that when the hydrological «warning» area

upstream is 100 square kilometres in size, planning of shutdowns downstream with sufficient forewarning is possible only if the downstream basin surface area is at least 1 500 km². Unfortunately, reliable predictions for turbine shutdowns based on hydrological factors would appear to be impossible in river basins comprising a number of hydrological regimes or those based on groundwater regimes. They are also very difficult for river basins with Mediterranean hydrological regimes. Concerning the minimum flow gradient required to predict a flow pulse downstream, it must be set for each river basin on the basis of a compromise to distinguish between real flow pulses and non-significant rises. Note that this minimum gradient was 13% of the IMF (interannual mean flow) over 24 hours for the Charente river, 15% for the Dronne and 20% for the Hérault rivers. Using these values, 15 to 35% of predicted flow pulses were still «false alerts».

On the whole, turbine shutdowns based on hydrological factors, in conjunction with more complex models using environmental parameters, are a worthwhile solution that can be implemented relatively simply in the river basins with the necessary characteristics, i.e. a significant part of the hydrographic network in France. The work on this topic must be pursued by launching an in-depth hydrological analysis of the most likely river basins in view of determining the best alert gradients. This approach could also be improved by integrating weather forecasts.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Part 2

Datasheets presenting project results and prospects for action

4 Projects for new knowledge

Knowledge on eel biology and behaviour lays the groundwork for devising and implementing management solutions for the protection of the species. The complexity of migratory phenomena in particular requires more research and study. During the research programme, special efforts were made to identify the factors determining downstream-migration conditions using considerable monitoring means, e.g. experimental fishing campaigns similar to that on the Dordogne river, as well as radio-telemetry and magnetic marking systems on the Rhine and Gave de Pau rivers. For upstream migration, new knowledge on migration rhythms was acquired via studies on technical solutions to overcome barriers.

KNOWLEDGE

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Development of a sampling protocol to determine eel downstream-migration rhythms in the Dordogne river

[Datasheet 1]

Scientific director:
Laurence Lissalde-Bonnet (EDF-CIH)

Net being lowered into the flume. © ECOGEA

1. General context of the project

It was decided to shut down the turbines at the Tuilières (Dordogne) hydroelectric plant at night and to open gates to provide eels with a bypass for their downstream migration. Lacking any precise knowledge on the migratory rhythms, this system was implemented every night from 1 September to 31 December. However, more knowledge on the migratory rhythms of eels and the main parameters governing migration was clearly required to minimise turbine shutdowns. To that end, experimental sampling catches were carried out approximately 20 kilometres upstream of Tuilières and measurement stations were created to gather data on environmental parameters.

2. Goals of the project

The goal of the project was to determine whether sampling catches were a feasible solution and, if yes, to gain knowledge on the migratory flows of eels in the Dordogne river and on the influence of environmental parameters such as the flow rate, water temperature, conductivity and turbidity, the moon phases, etc.

3. Study sites - Methods

The experimental fishing campaigns took place in the flume supplying the Mauzac hydroelectric plant. «Guideau» nets were used, which are commonly employed by commercial fishermen to catch eels during their downstream migration in the Loire river. The net was lowered from a platform in the flume. The platform consisted of large blocks of plastic on which various devices (lifts, winches, etc.) could be mounted. The guideau net was attached to the platform and lowered into the water current for several hours to catch eels heading downstream. The net, 6 metres wide and 3 high (18 square metres),

Aerial view of the Mauzac plant (© EDF).

blocked approximately 10% of the flume which is 35 metres wide and 5 deep (175 square metres). The eels were recovered from the net using a boot to which the extreme downstream end of the net was lifted. The netting installation was designed and operated by professional fishermen whose experience and know-how turned out to be indispensable.

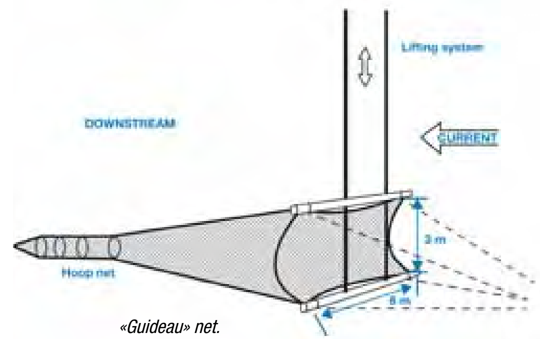
The flume upstream of the plant (© ECOGEA).

4. Results of the project

The experimental fishing work did not encounter any particular problems during the two monitoring campaigns. A total of 214 eels were caught during 140 nights the first year (from 1 September 2009 to 26 January 2010) and 118 eels were caught during 122 nights the second year (from 8 November 2010 to 13 March 2011).

The CMR (capture-mark-recapture) technique was used the first year to estimate the effectiveness of the fishing campaigns. The results came in at 8%, which is close to the size of the net compared to the flume (10%). It turned out that the position of the platform in the flume was an important factor in its effectiveness. The position was optimised using the results of a radio-monitoring project that revealed the preferred trajectories of eels in the flume.
Analysis of the initial results (2009-2010 and 2010-2011 campaigns) would appear to show that the selected period (1 September - 31 December) does not include the main peaks in downstream migration which take place later in the season (January and February).

The campaigns also served to collect data on the influence of environmental parameters (essentially the flow rate and turbidity) on the timing of downstream migration and to develop preliminary «models» to predict downstream-migration periods. The capture data was used to check model results (effective presence or absence of eels) during the operational start-up of the predictive models in 2011.



«Guideau» net.

5. Use for operational management

Field of application. Knowledge on downstream-migration rhythms of silver eels

Technology transfer. The sampling technique using guideau nets was well suited to gathering data on the downstream-migration rhythms of silver eels in rivers the size of the Dordogne (interannual mean flow rate = 280 m³/s). The installation in the flume of a hydroelectric plant is advantageous due to the smaller cross-sectional area and to the fact that the flow velocities are generally compatible with operation of the «guideau» net a majority of the time.
A smaller cross-sectional area is necessary for this type of experimental fishing campaign in order to cover a larger percentage of the downstream flow. When the nets are located in the flume of a hydroelectric plant, discharges via the dam (with escaping eels) must be limited to avoid disturbing the catch results. It should be noted that the low velocities during low-flow periods can render the operation of guideau nets difficult and even impossible.
This type of fishing campaign is expensive (approximately 50 000 euros for the entire installation) and requires considerable human resources because a team of at least two people must be on hand every night for twelve hours (six in the evening until six in the morning) and for at least four months.

Partners: ECOGEA, Garonne-basin association of professional fishermen (AAIPPBG)

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Determining how eels overcome a series of obstacles on the Rhine

Scientific director:
Eric de Oliveira (EDF R&D – LNHE)

Nedap station supplied by solar panels. The three antenna cables are visible on the bank. © E. de Oliveira

1. General context of the project

During downstream migration in a river, eels can pass through hydroelectric installations either via the turbines, in which case they can suffer high mortality rates, depending on the type of turbine, or via the spillway without any damage. Passage through one or the other channel depends on the site configuration and on the hydrology of the river. Determining which channel the eels take is a fundamental factor in estimating the potential damage inflicted by hydroelectric installations on a given river.

2. Goals of the project

The purpose of this experiment was to gain knowledge on the conditions created by the presence of hydroelectric installations for the downstream migration of silver eels in a major river such as the Rhine. The desired knowledge concerned the dynamics of downstream migration depending on the environmental parameters of the river, the distribution of the fish between the different channels through hydroelectric installations and the speed of downstream migration depending on the river hydrology. In addition, a branch of the Rhine, the «Old Rhine», served to analyse downstream-migration dynamics along a 53-kilometre section without any hydroelectric installations.

3. Study sites - Methods

Migration rhythms were studied using the NEDAP TRAIL® technique, which is based on radio-frequency identification. This technique was selected following a feasibility study carried out on the Rhine. The Nedap technique involves equipping eels with a transponder (implanted internally), releasing them upstream of the monitored zone and detecting their passage thanks to fixed detection stations carefully positioned along the banks. The stations are connected to antenna cables that cross the river bottom, perpendicular to the flow.

A complete investigation of the various channels through the ten installations in the French part of the Rhine (dam, hydroelectric plant and navigation locks) would require the installation of 29 or 30 detection stations. Given the high cost of each station as well as a number of uncertainties concerning study implementation and the interpretation of the results, nine stations were purchased and six have been installed since 2009. This set of six antennas was sufficient to:

- determine in detail the distribution of fish between the various channels on the Kembs site (plant, lock, dam);
- count the number of fish travelling down the GCA (Alsatian grand canal) comprising four hydroelectric plants;
- count the number of fish travelling down the Old Rhine, a branch free of obstacles and parallel to the GCA;
- analyse migration rhythms in the two branches, GCA and Old Rhine, as a function of environmental parameters (flow rates, temperature, turbidity, etc.).

The Iffezheim site, the furthest downstream, will be equipped in 2012. It is also possible to use stations already installed in Germany and Holland to monitor the fish to the Rhine estuary. In addition, measurement stations for water turbidity, conductivity, temperature and the luminous intensity have already been installed by EDF along the Rhine. The volumes passing through the turbines and released by the dams are also known.

4. Results of the project

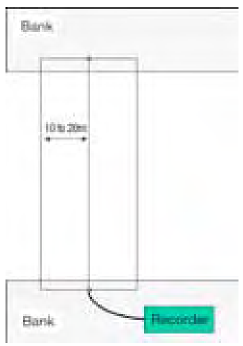
During the first two campaigns (2009-2010 and 2010-2011), numerous problems were encountered in setting up the stations, including antenna cables torn up by boat anchors, incompatible electronic components, transmitter battery problems, etc. A majority of these problems were solved and the stations may now be considered operational. As of July 2011, the data showed that the antenna that encountered the most problems operated only 23% of the time since its installation, compared to 96% for the antenna with the fewest problems.

The main problem during the past season was the malfunction of 115 transponders out of the 142 in service because they had self-activated during storage and discharged their batteries. Subsequently, a protocol for testing prior to installation was drafted and validated with the Nedap company.

Given the very low number of fish monitored to date, it is difficult to draw any conclusions concerning the distribution of migratory flows as a function of environmental parameters. That being said, a few results are available. Out of the 27 fish that were captured and marked, 20 started their migration. According to data at the Kembs site, 75% of the eels migrated via the hydroelectric plant (GCA) and 25% via the dam (Old Rhine). A total of 50% of the migrating eels arrived downstream of the Vogelgrun plant, i.e. they travelled the entire Old Rhine or succeeded in passing the four plants along the GCA. A single fish was detected by the antenna furthest downstream a day and a half after being released and having travelled over 90 kilometres. For the fish travelling via the GCA (50 kilometres), their downstream migration times ranged from 13 hours to a bit less than three months.

These results are strictly temporary. It will be necessary to monitor a larger number of fish and obtain results over several years in order to produce better data on the downstream-migration conditions. The goal for 2011-2012 is to capture and mark a much larger number of eels before releasing them upstream of the Kembs site and the Old Rhine.

Nedap stations (numbered 1 to 7) and environmental measurement stations (red points).



Layout of a Nedap station.

5. Use for operational management

Field of application. Knowledge on downstream-migration rhythms of silver eels.

Technology transfer. For large rivers such as the Rhine, the Nedap system is well suited to measuring the distribution of eels migrating via either the spillways/bypasses or the turbines or the locks. However, a certain level of experience is required in implementing the technique, in terms of station set-up and the characteristics of the transponders.

Given that it is not possible to monitor individual fish manually between the detection stations and that this technique does not take into account fish halting their migration, predation, etc., a large number of fish must be captured and marked to produce reliable results. The Nedap technique alone cannot quantify the mortality of the eels passing through the turbines. It can simply indicate the number of fish travelling via the channels equipped with antennas. Again, for these reasons, a large number of fish must be monitored over a period of several years. Another limit to the use of the technique is the high cost of the detection stations and their installation, which totals about 200 000 euros per station.

Prospects. This project, combined with the knowledge obtained on the mortality rates of eels passing through the turbines (predictive models and *in situ* measurements), should make it possible to estimate the numbers of migrating eels succeeding on overcoming the installations on the French Rhine and provide information on the environmental conditions conducive to the migration of silver eels. To achieve those results, the plan is to equip and release over 300 eels each year over the next four or five years.

Partners: Onema, Association Saumon Rhin, Rhine-Meuse water agency (co-sponsor of the project), Petite Camargue Alsacienne, NEDAP

For more information… http://www.nedaptrail.com/

Contact: Eric De Oliveira (eric.de-oliveira@edf.fr), Sébastien Manné (sebastien.manne@onema.fr)

Study of eel downstream migration and passage of hydroelectric installations on the Gave de Pau river

Scientific directors:
Michel Larinier (Onema), Frédérique Bau (Irstea), Philippe Baran (Onema), François Travade (EDF).

Hydroelectric plant seen from upstream. © P. Gomes

1. General context of the project

Hydroelectric installations can harm eels during their downstream migration, particularly if they pass through the turbines. Quantification of the damage depends on in-depth knowledge of the migration conditions, the distribution of the fish in the various channels through the installations and the mortality rate of the fish passing through the turbines. This study corresponds to a project in the Eels and installations R&D programme, which attempted to determine how silver eels overcome a series of hydroelectric obstacles in a section of a given river. The project pursued the work launched in 2004 on the Gave de Pau river, using radio-monitoring techniques to precisely determine the behaviour of the species, essentially at a hydroelectric installation (Baigts plant) (Travade *et al.*, 2009, 2010).

2. Goals of the project

The goals of the project were to:

- determine the links between the migration of silver eels in a river and environmental parameters, notably the hydrological conditions;
- learn more about the behaviour of eels upstream of hydroelectric installations and determine the channels travelled (turbines, spillways, bypasses, fish passes);
- develop models capable of predicting the channels travelled as a function of installation characteristics and environmental characteristics.

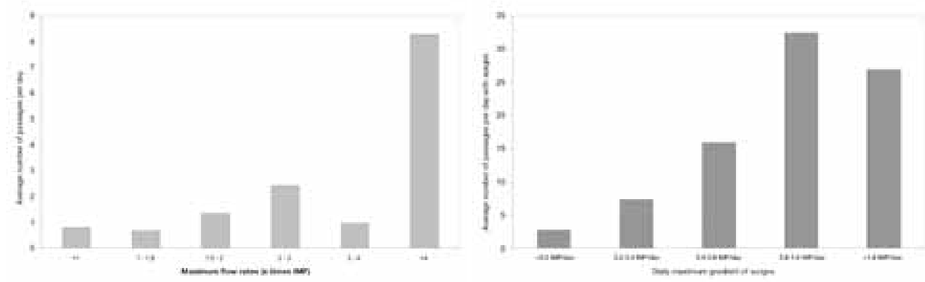
3. Study sites - Methods

The study was carried out from 2007 to 2010 on a 60-kilometre section of the Gave de Pau river between Jurançon and Puyoo (interannual mean flow IMF = 82 m³/s) with six hydroelectric installations (turbine flows ranging from 20 to 110 m³/s). A total of 192 silver eels were radio monitored over a period of four to five months each year. Sets of receiving antennas set up along the river next to each hydroelectric installation precisely determined the passage times of the fish through the installations and, above all, the channels travelled. It was possible to establish links between the behaviour of the eels on the one hand, and variations in certain environmental parameters (hydrology, conductivity, temperature, turbidity) and the operation of the hydroelectric plants on the other. Statistical processing with a general linear model (GLM) was used to produce methods to predict the channel (turbines, spillways) in a hydroelectric installation travelled by silver eels.

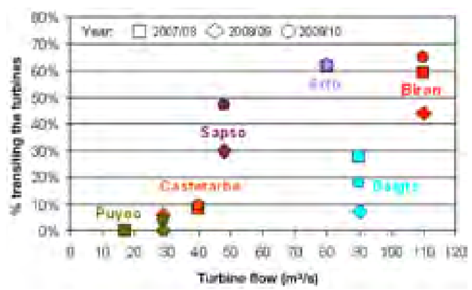
4. Results of the project

Migratory activity of eels

The migratory activity of the eels was estimated based on the number of eels passing through an installation per day of monitoring. A total of 562 passages by the marked eels were detected. The flow rates at which the fish passed through the installations varied widely, from 25 m³/s (low-flow rate) to 529 m³/s (cubic metres per second). Half of the passages occurred when flow rates were at least double the interannual mean flow (IMF) and 90% occurred during changes in the flow rate (37% of the time), with a majority of passages (83%) occurring when water volumes were increasing. Migratory activity was strongly correlated to the daily flow gradient and to the maximum value reached by surges in flow rates. It was also characterised by alternating periods of high activity (travel downstream) and low activity during which the eels may remain perfectly immobile for several days. Passages generally took place during the night with 83% occurring between 17.00 in the afternoon and 8.00 the next morning. The mean velocity of downstream migration was 3 km/hour, but with significant differences between individual fish and river sections (0.4 to 6 km/h). The velocity also depended heavily on the hydrological conditions.



Downstream-migration activity of eels as a function of the maximum flow rate and the daily gradient.

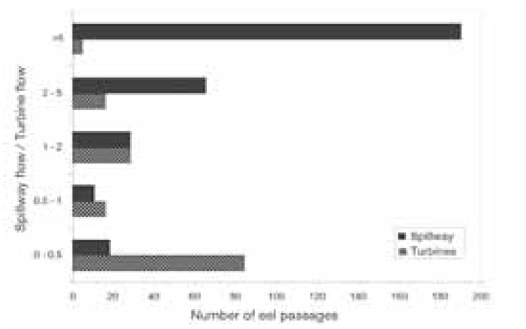


Number of eels transiting the turbines as a function of the turbine flows in each installation.

Channels travelled by eels through hydroelectric installations

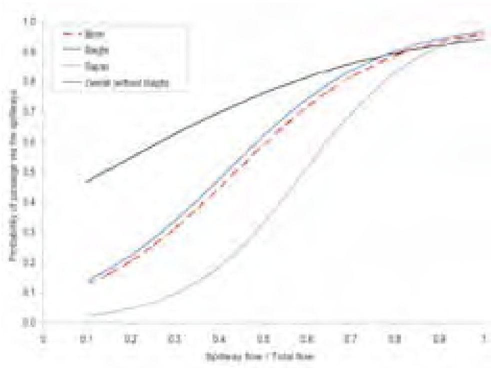
Taking the six installations as a whole, 65% of passages took place via the spillways, 32% via the turbines and 3% via other channels (bypasses, fish passes). These values vary significantly depending on the hydroelectric installation (passage via the turbines varies from 2 to 62%), i.e. essentially the turbine flows, the spacing between bars at water intakes (in the plants where the spaces are smaller), management of surges, the configuration of the water intakes and spillway, and the position of the installation on the river section with respect to where the eels were released.

The channels travelled by the fish through hydroelectric installations depend heavily on the relative flow rates in the water intakes (turbines) and the spillways when the eels arrive just upstream of the installation.
The greater the amount of water flowing via the spillway, the higher the percentage of eels travelling via the spillway, i.e. avoiding the turbines. The surface bypasses used for the downstream migration of salmonids were less effective for eels than for smolts, but they may nonetheless represent a non-negligible means for eels to avoid the turbines (up to 20% of passages on the Baigts site), notably on sites where the bars on the water intakes tend to dissuade the fish, i.e. sites where the distance between bars is less than 3 centimetres.



Number of eels passing through the spillways or the turbines as a function of the relative flows via the spillways and the turbines..

The statistical analysis of the data from the six installations served to develop models to estimate the probability of silver eels transiting the turbines during downstream migration as a function of the hydrological conditions and particularly the ratio between spillway flows and the total river flow. The higher the ratio, the higher the probability that the eels avoid the turbines. The models differ depending on the installations, notably the distance between the bars on water intakes (small at Baigts) and the overall configuration of the dam (Sapso). For an identical ratio (0.5), the passage of the eels via the spillways can vary from 33% to 76%, depending on the site.



Model of the probability of passage via the spillway as a function of the ratio between the spillway flow and the total river flow.

5. Use for operational management

Field of application. Evaluation of the impact of hydroelectric installations on the downstream migration of silver eels.

Technology transfer. This project produced new knowledge on the behaviour of eels upstream of hydroelectric installations during their downstream migration. It provided information on eel passage via the spillways and developed tools to estimate spillway passage as a function of hydrological conditions and the relative flow rates at the water intakes. The project also confirmed the importance of the specific configuration of each installation and notably the spaces between the bars of the water intakes and the general configuration of the spillway.

The results served to prepare the groundwork for a diagnostics tool to determine the impact of a series of hydroelectric installations along an entire river section. The bypasses for downstream migration that exist for smolts may, on some sites, represent a non-negligible contribution for eels to avoid the turbines and it is recommended that they be used during eel migratory periods.

Partners: Topwatt, Société Hydroélectrique et Immobilière du Sud, SUO Energie, Migradour

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5 Diagnostic tools required for management

On all management and work scales, ranging from the national to each local installation via the river basins and districts, diagnostic tools capable of evaluating the impact of human activities in an open and clear manner for all stakeholders are required. In terms of obstacles blocking rivers, a major research effort was made to determine the effectiveness of upstream-migration systems and to quantify the impact of hydroelectric installations on downstream migration. The research programme focussed on creating tools to assess turbine mortalities in conjunction with models to calculate the distribution of eels passing through the water intakes (turbines) and other channels during their downstream migration. This work produced a set of tools that now make it possible to calculate the cumulative impact of installations for entire river basins.

DIAGNOSTICS

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Capture-mark-recapture and evaluation of the effectiveness of a specific type of fish pass

[Datasheet 4]

Scientific directors:
Christian Rigaud (Cemagref), Hilaire Drouineau (Cemagref), Philippe Baran (Onema).

Pas du Bouc weir. © C. Rigaud

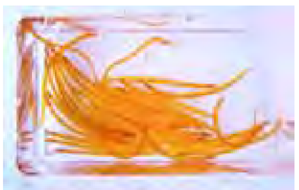
1. General context of the project

Monitoring of a fish pass always produces results showing eel migration over a relatively short time period (two to three months) and a fairly small range of fish sizes, with spikes in the numbers of passages. However, there always remains a degree of uncertainty concerning the correlation between the observed numbers and the actual numbers of migrating eels arriving at the foot of the installation. The CMR (capture-mark-recapture) technique on an equipped site consists of releasing a known number of marked eels at different spots downstream of an installation, then observing and analysing how many eels make their way to the fish pass and the flow dynamics of their travel. This strategy depends on the marking technique having a minimal impact on fish behaviour. The types of marking systems used depend on the size of the fish.

Since 1999, Migado (Lauronce *et al.*, 2011) has pit-tagged (a tag with an electronic ID code) 10 300 eels 25 to 35 centimetres in size at the EDF Golfech and Tuillières dams and released them two to three kilometres downstream. Recaptures span long periods (up to seven years after marking) and the annual probability of recapture varies depending on the site and the year (0.08 (±0.08 with a maximum of 0.29) at Golfech and 0.03 (±0.04 with a maximum of 0.15) at Tuillières. These results indicate travel based more on trial and error depending to the given conditions than a pressing need to migrate.

At the Arzal dam, Briand (Briand *et al.*, 2005) marked glass eels with a vital dye (the colour persists for two weeks). Recaptures took place over a week following the release. The fish pass enabled effective daily passage of an estimated 4% of the active fish stock and an overall passage of 30% of the active stock arriving after the closing of the fishing season. A second fish pass subsequently installed on the opposite bank represented only 14% of the detected passages (Anonymous, 2008).

Marking of glass eels using a vital dye. © Irstea



VIE (visible implant elastomer) tags can be used on all sizes of fish. © Irstea

2. Goals of the project

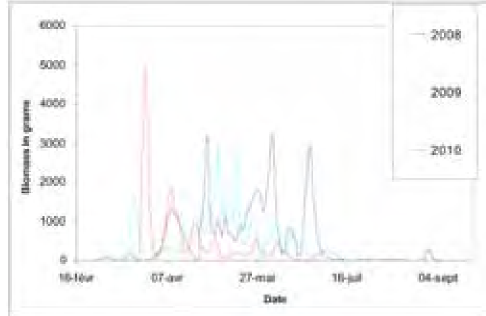
VIE (visible implant elastomer) tags, that had previously been tested to ensure minimal impact on fish behaviour (Imbert *et al.*, 2005), were then used on eels less than 15 cm in length to observe their behaviour at three installations equipped with special fish passes and subject to tides or located very close to the tidal limit. The goal was to evaluate the accessibility and the facility of passage at each installation.

3. Study sites - Methods

Two installations are subject to tides (Riberou on the Seudre river, Enfreneaux on the Sèvre niortaise river) and the third is located just upstream of the tidal limit (4 kilometres upstream at Pas du Bouc on the Porge canal).

The sites are monitored very regularly (daily or every two days) by the local operators (fishing federations of the Charente-Maritime and Gironde departments, Marais Poitevin regional park) over the entire period that the fish passes are in operation.

Analysis of the passage data confirms the existence of a definite migratory period with spikes in the numbers of passages and clearly reveals the influence of certain environmental factors such as the temperature, flow rate and tidal coefficients on the start of the migratory season and on its development.



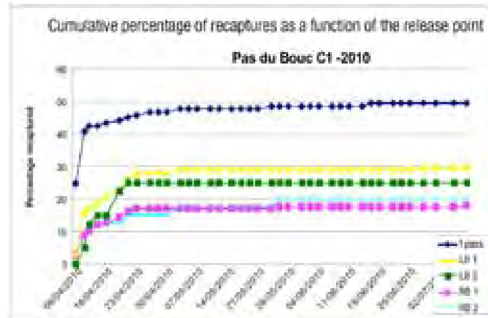
Distribution of eel passages observed from 2008 to 2010 at Pas du Bouc (Gironde fishing federation).

During each campaign, 600 captured fish were examined (size, weight, health status), then marked and placed in three groups. The first was released at the foot of the fish pass, the two others were released about 50 metres downstream, one near the left bank, the other near the right bank. A control group (marked and unmarked) was held in observation for six days. The mortality of the marked fish was always under 1%. Following the release, the fish caught in the pass-traps were systematically checked for fluorescent markings using an UV lamp (resulting in processing times 50% longer than for standard procedures). The marked fish were then measured and examined prior to being released well upstream of the installation.

4. Results of the project

On all sites, the various groups of fish were recaptured according to fairly similar rhythms, i.e. with a difference between the group released at the foot of the pass and the other two downstream groups and with most recaptures taking place within ten days. The cumulative difference in recaptures varied depending on the site and the number of times the test was repeated.

In the example shown opposite (Pas du Bouc, April 2010), the downstream groups near the left and right banks were doubled (the marked fish came from either the trap (group 1) or from an electric-fishing campaign (group 2) at the foot of the dam). That did not significantly alter the recapture results for the two downstream zones.

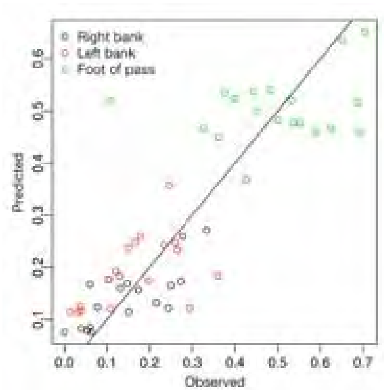


Cumulative recaptures of marked glass eels after being released at the foot of the Pas du Bouc fish pass and further downstream.

p passe : Foot of pass
RG : Left bank 1
pê RG : Left bank 2
RD : Right bank 1
pê RD : Right bank 2

The analysis of the recapture numbers for the downstream groups and the comparison with the group released at the foot of the fish pass indicates a high degree of variability between sites and within sites. This variability is caused by different operating situations (river, estuaries), differences in the resumption of migratory activity depending on the campaign and different levels of access to the fish passes not only between sites, but also between campaigns on a given site.

Site	Number of campaigns	Percentage recaptured of downstream groups	Recapture ratio of downstream groups to foot-of-pass group
Pas du Bouc (river)	9	22% (± 10) / Maxi 45%	0.48 (± 0.24) / Maxi 0.89
Enfreneaux (estuary)	3	24% (± 6) / Maxi 31%	0.72 (± 0.18) / Maxi 0.86
Ribérou (estuary)	5	41% (± 17) / Maxi 67%	0.90 (± 0.28) / Maxi 0.94



Model of the probability of recapture of marked glass eels released downstream and at the foot of a fish pass as a function of various individual and environmental criteria (size and condition of individuals, point of release, depth of water, temperature, cloud cover, day in lunar month, etc.).

It would appear that following a marking operation, not all the fish released at the foot of the fish pass resume their migration, at least not immediately. Resumption of migratory activity depends on the campaign, but remains on the whole comparable between the groups. Finally, the comparison between the foot-of-pass and downstream numbers will provide information on the accessibility of the fish pass, which may vary depending on the moment.

To determine the relative importance of the various factors (size and condition of individuals, point of release, depth of water, temperature, cloud cover, day in lunar month, etc.), Bayesian analysis was used on one site (Pas de Bouc, river).

The model is based on dividing the itinerary of a fish into sections, from its release to its arrival in the trap several days later (living fish resuming migratory activity, accessing the foot of the pass, travelling through the pass), with a tested probability factor attributed to each section.

Using a «Step DIC» procedure to retain only the main parameters, the model clearly identified a high and steady flow rate via the dam and a high water level at the foot of the pass as the decisive parameters determining the probability of reaching the foot of the pass for the downstream groups, with the left-bank groups always having a slightly better chance.

5. Use for operational management

Field of application. Evaluating the transitability of an installation.

Technology transfer.

- Provision of local information to integrate eel migration in the hydraulic management of the installation.
- The feasibility of the marking strategy was tested, however, a number of constraints were noted (long marking operations and subsequent identification of the fish in the trap) that will limit its use to a few test sites. The project revealed the importance of holding the fish in an inspection tank for one week (cases of direct mortality) and of releasing a group in the immediate vicinity of the fish pass. It also made clear the absolute necessity of taking the migratory activity of individual fish into account when analysing the results of CMR operations.

Prospects. The model will be adapted and tested in the two estuaries (Ribérou and Enfreneaux) and may be used again in similar operations.

Partners: Gironde and Charente-Maritime fishing federations, Charente-Seudre migratory group, Marais Poitevin regional park

For more information…

RIGAUD C., BARAN P., DROUINEAU H., ROQUEPLO C., LAMARQUE E., FABRE R., ALRIC A., LAHARANNE A., ROUET M., Der MIKAELIAN S., 2012. Marquage-recapture et évaluation de l'efficacité d'un dispositif de franchissement sur un ouvrage estuarien ou proche de la limite de marée. Rapport Pôle Eco-hydraulique – Programme R&D Anguilles/Ouvrages.

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Development and testing of an automatic resistive counter for elvers

[Datasheet 5]

Scientific director:
François Travade (EDF R&D)

Resistive counter. © L. Carry, MIGADO

1. General context of the project

It is important to count the fish transiting fish passes not only to determine the effectiveness of the pass, but also to gather biological information on the migrating population. In special «brush passes supplied with pumped water» for eels, it is easy to trap the fish for counting purposes, but the process requires large amounts of labour and does not provide very precise information on migratory rhythms.
For those reasons, an automatic resistive counter was developed in 1997 by the ELTA company (formerly ELFES), at the request of EDF R&D and the High council on fisheries (now Onema). The counter is based on the difference in conductivity between fish and water. The fish are counted and their size is determined by analysing the variations in conductivity detected by electrodes positioned in the water along the path followed by the fish. The counter was put through *in situ* tests and progressively developed and upgraded until the final version was produced in 2007.

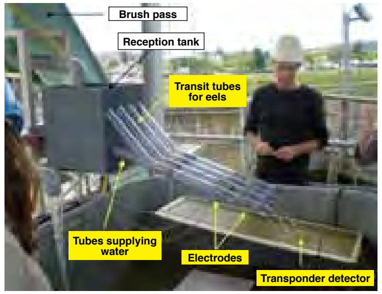
2. Goals of the project

The goal of this project was to validate *in situ* the final version of the resistive counter.

3. Study sites - Methods

The ELFES-ELTA counter (see the photos below) is made up of a sensor with four tubes equipped with electrodes leading from a reception tank and an electronic unit that analyses the conductivity in each tube, counts the eels, determines their size and stores the data. For each eel detected, the counter registers the time of passage and the value of the conductivity signal which later serves to calculate the size and weight of the eel using a calibration chart that must be adapted to each site. The reception tank, to which the counter is attached, is located at the top exit of the brush pass which receives pumped water. The elvers fall into the reception tank and then pass through one of the four tubes. A constant flow rate (0.1 litre per minute) is maintained in each tube.

The counter was installed on the brush pass at the EDF Golfech hydroelectric plant (Garonne river), just upstream of a trap that served to check the validity of the elver counter results (number and size of elvers). The tests were run over three migratory seasons (May to July) from 2008 to 2010.

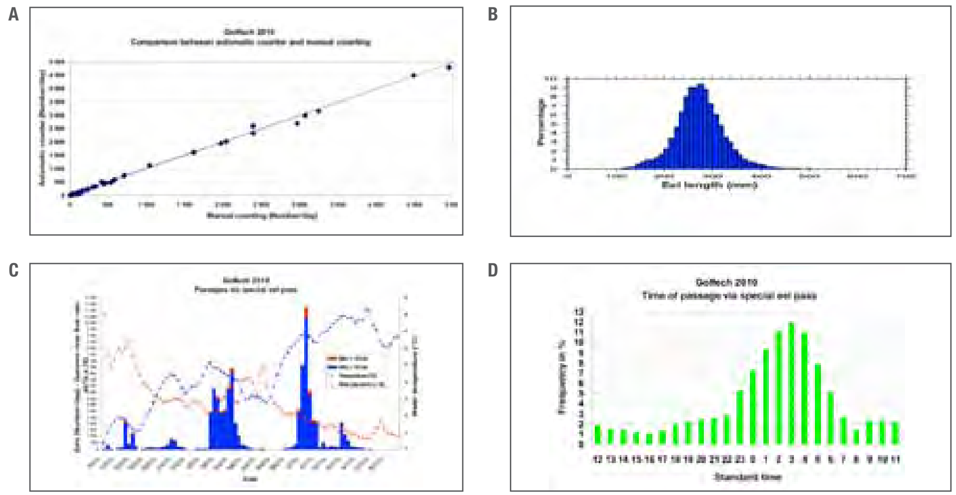


ELFES-ELTA electronic counter installed at the head of the Golfech fish pass for elvers. © L. Carry, MIGADO

Electronic unit of the ELFES-ELTA counter. © F. Travade, EDF

4. Results of the project

The tests validated the accuracy of the elver counter (number and size of elvers).
- The counter can detect elvers that are at least 125 millimetres in length. Detection is partial (10 to 90%) for lengths from 125 to 160 mm and total for fish above 160 mm.
- The counting function is extremely reliable with a detection rate higher than 99% for several thousand passages (checks were run on 38 000 fish in 2010 and on 59 000 in 2008), with daily peaks above 11 000 fish and hourly peaks of approximately 1 600 fish.
- Biometrical results (size and weight of the fish) derived from the signal recorded by the counter are very satisfactory when characterising an entire migratory population (several dozen fish). However, the data is insufficiently precise to accurately measure very small groups of fish.



Results obtained using the ELFES-ELTA counter on the fish pass at the Golfech hydroelectric plant in 2010. Comparison between automatic and manual counts (A) and examples of biological results, i.e. length of eels transiting the fish pass (B), daily passages (C) and hourly passages (D).

5. Use for operational management

Field of application. Evaluating the effectiveness of a fish pass and monitoring eel stocks.

Technology transfer. The counter is perfectly suited to acquiring accurate biological data on various time scales (hour, day, year) for elvers longer than 125 mm.
The counter requires electrical power (220 Volts) and frequent monitoring (two to three times weekly) to check a number of parameters, e.g. the flow rate in the tubes and the quality of the data recorded.

On major migratory sites (daily peaks above 5 000 fish), a micro-computer must be added to the system for data storage. One to two days are required at the end of each migratory season to validate and sort the data.

The cost of a complete system is approximately nine to ten thousand euros, depending on the options included (GSM for data transfer, installation, etc.).

The drawback to the counter lies in its inability to detect eels shorter than 125 mm. It is therefore necessary to correct the count data by carrying out regular biometrical measurements in order to calculate the non-detected part of the population.

Prospects. It would be worthwhile to pursue the development of this type of counter in view of counting small glass eels and elvers.

Partners: MIGADO (Laurent Carry)

For more information…

Technical note. ELFES-ELTA automatic resistive counter for eels. Development work in a lab, followed by *in situ* tests. EDF-MIGADO report to be published.

The counter system is marketed by the Kraft Werk company (kraftwerk2@wanadoo.fr).

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In situ evaluation of eel mortality in large turbines

Scientific directors:
Eric de Oliveira (EDF R&D – LNHE),
Franck Pressiat (CNR ingenierie).

Large turbine. © M. Zylberblat

1. General context of the project

In order to develop models capable of predicting the mortality rates of eels transiting turbines, it is necessary to measure actual mortality rates *in situ*. There are very few experimental results available to date for large turbines, thus making it difficult to extrapolate existing equations.

2. Goals of the project

The goal was to quantify *in situ* the mortality and injury rates of eels migrating downstream through two types of large turbines (Kaplan and Bulb turbines) that are common in hydroelectric installations on the Rhine and Rhone rivers.

3. Study sites - Methods

Turbines on three sites were selected for the tests, namely two Kaplan turbines (4 and 5 blades) on the Rhine river and a Bulb turbine on the Rhone. The tests on the Rhine turbines were carried out under the responsibility of EDF in 2009 and 2010, the test on the Rhone turbine was run by CNR (Rhone-river agency) in 2010. The fish used for the tests were representative of silver eels migrating downstream, i.e. 60 to 90 centimetres long with an average size of approximately 70 cm.

A CMR (capture-mark-recapture) technique combined with another method to estimate *in situ* eel mortality was used to measure mortality/survival rates of eels transiting large turbines such as those installed on the Rhine and Rhone rivers. The technique, called HI-Z tag, was developed by Normandeau Associates Inc., an engineering firm in the U.S. A precise number of fish were injected in the intake as close as possible to the turbine and then recaptured downstream. The fish were first equipped with small balloons that inflated after passing through the turbine and lifted the fish to the surface where they could be recaptured. Each fish was then examined and subsequently put into a holding tank for 48 hours prior to a second examination to check for any delayed mortalities. A description of any injuries and lesions was recorded to determine the causes. The survival rate one hour and 48 hours after the injection into the turbines, the number of injuries and the number of fish without any injuries were calculated.

Two injection systems are required. The first, installed upstream, injects the fish as close as possible to the turbines. The second, installed downstream (i.e. the fish do not transit the turbine), serves to check that the marking and the injection systems do not injure or kill the fish (i.e. do not incorrectly increase the injury and mortality rates attributed to the turbines). The marking and injection systems must be strictly identical. They were manufactured by EDF R&D with assistance from the Normandeau Associates company and were used for all three tests. The first test, carried out at Fessenheim on the Rhine, served to adapt and validate the protocol between EDF R&D and Normandeau Associates.

Marking tank and injection system. © E. de Oliveira

Capturing the eels downstream of the plant. © E. de Oliveira

A minimum of 350 eels were used for each test. Approximately 300 fish were injected in the turbines on each site and a control group of 50 were injected downstream to avoid the turbines.

4. Results of the project

The high recapture rates (96% at Fessenheim, 98% at Ottmarsheim, 95% at Beaucaire) combined with the high survival rates of the control group not transiting the turbines, (98.6% at Fessenheim, 100% at Ottmarsheim, 100% at Beaucaire) signify that the survival and injury rates for the turbines are valid and accurate (±5%). The results are summarised below.

Plant	Characteristics of turbines and			Survival rate installations		Injury rate	Percentage of uninjured individuals
	Diameter	RPM	Head	1 hour	48 hours		
Fessenheim Kaplan 4 blades	6.67m	88.2	15.7 m	93.2%	92.4%	7.4 %	92.6%
Ottmarsheim Kaplan 5 blades	6.25m	93.7	15.5 m	82.6%	78.6%	27.6%	72.5%
Beaucaire Bulb 4 blades	6.24	94	16 m	95.6%	92.3%	8.4%	91.6%

Injuries and mortalities are thought to be caused primarily by the eels entering into contact with the turbine blades or other structural components. At Fessenheim and Beaucaire, the mortality rates were lower than expected given similar tests carried out on other sites (U.S., Canada, Netherlands, etc.), where the rates ranged from 15 to 25%.

The injury and mortality rates at Ottmarsheim were higher than on the other two sites. These results are difficult to explain given the knowledge currently available. The number of blades would appear to explain the differences at least in part, however other tests run by Normandeau Associates on pike produced contrary results concerning the link between injury rates and the number of turbine blades.

[Datasheet 6]

5. Use for operational management

Field of application. Evaluating the impact of hydroelectric installations.

Transfert technologique. Technology transfer. The results obtained will be used to further develop and improve the accuracy of the models predicting the mortality of eels transiting these types of large turbines. By combining these results with knowledge on how silver eels migrate downstream and on their distribution in the various channels through hydroelectric plants (turbines, locks, spillways), it will be possible to determine more accurately the impact of hydroelectric plants installed on large rivers on eel populations migrating downstream. The significant differences in the results obtained on 4-blade and 5-blade turbines will require more research to improve the predictive models. The shape of the blades would also seem to have a large impact on mortality rates and must be taken into account.

Prospects. The shape of turbine blades will require more research because the thinner the blades, the greater the risk of injury. This *in situ* result was confirmed by lab tests in the U.S. The above results and the uncertainty surrounding the causes require research to understand the observed differences. To that end, precise drawings of the blades in the tested turbines will be obtained and meetings have been set up with the turbine manufacturer and Onema.

Partners: Onema, Normandeau Associates, Association Saumon Rhin, Rhine-Meuse water agency (co-sponsor of the project), Association Migrateurs Rhône Méditerranée, Petite Camargue Alsacienne nature reserve

For more information…

Mathur, D.,P.G. Heisey, E.T. Euston, J.R. Skalski, and S. Hays. 1996. Turbine passage survival estimation for Chinook salmon smolts (Oncorhynchus tsawytscha) at a large dam on the Columbia River. Can. Jour. Fish. Aquat. Sci. 53:542-549.

Contacts: Eric De Oliveira (eric.de-oliveira@edf.fr), Sébastien Manné (sebastien.manne@onema.fr)
Franck Pressiat (f.pressiat@cnr.tm.fr), Marc Zylberblat (m.zylberblat@cnr.tm.fr)

Models to predict eel mortality during transit of Kaplan turbines

Scientific directors:
Peggy Gomes (Onema),
Michel Larinier, (Onema).

Hydroelectric plant seen from downstream. © P. Gomes

1. General context of the project

An evaluation of the impact of hydroelectric installations is an indispensable part of efforts to determine the percentage of eels surviving migration along entire river sections. The impact of a hydroelectric plant depends on the probability of fish being drawn into the water intakes (which itself depends on the plant configuration, on the turbine flow and on the overall flow conditions during the downstream migration), as well as on the injuries and mortalities inflicted on that part of the fish stock transiting the turbines. However, evaluations involving *in situ* experiments on the potential harm inflicted by passage through turbines are not possible for each installation given the high cost and the resources required for each evaluation. The potential damage caused by a turbine can nonetheless be roughly estimated by extrapolating the results of tests on similar turbines or by using predictive models developed using the experimental results obtained on other sites.

2. Goals of the project

The goals of the project were to:
- collect and analyse all the available data in the scientific and technical literature on the harm caused to eels by Kaplan turbines;
- determine the main factors likely to cause injury and mortality;
- develop models capable of predicting mortality rates based on the results of successful experimental tests.

3. Study sites - Methods

This work used the data from experiments carried out on 24 sites in Europe and North America and was divided into the steps listed below.

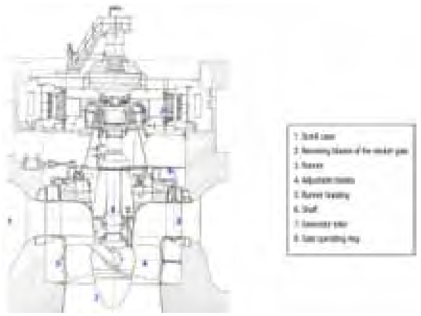
- Critically analyse the 71 tests run on 15 sites for which all the necessary information was available and select the relevant tests (29 tests with the turbine blades as open as possible).

- Compile the test data concerning mortality rates, turbine characteristics (head, nominal flow rate, number of blades, diameter, etc.) and operating characteristics during the test (flow rate, opening of the wicket gate).

- Analyse mortality factors and study the various approaches to developing predictive models.

- Use statistical processing to formulate the models.

- Validate the resulting models by running tests on 67 turbines operating in France for the most part.



Drawing of a Kaplan turbine for the Ottmarsheim installation (detail of a drawing by Vivier, 1966).

Runner of a three-blade Kaplan turbine. © M. Larinier

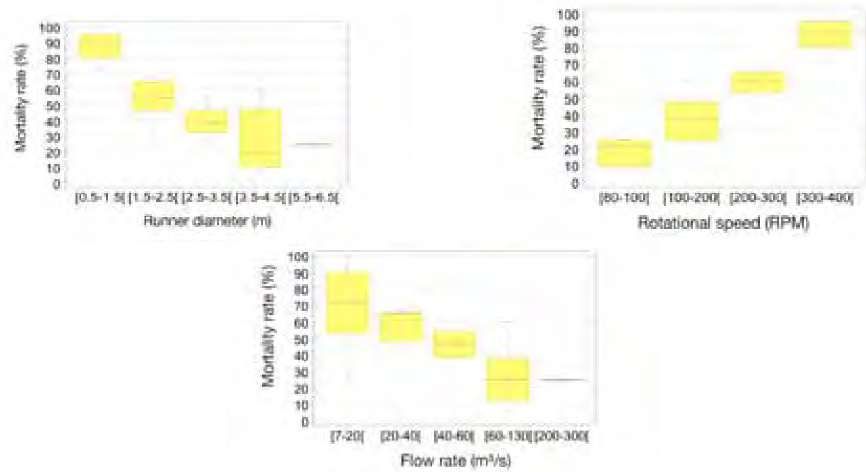
4. Results of the project

The experiments revealed highly variable mortality rates depending on the sites and on the types of turbine. Generally speaking, injury and mortality rates increased with the size of the eels and the rotational speed of the turbines, and decreased for smaller turbine diameters and lower nominal flow rates. Mortality rates ranged from 5% to 10% for large, low-head turbines and exceeded 80% for small Kaplan turbines with high rotational speeds.
Three mathematical models were developed on the basis of tests carried out with flow rates higher than 70% of turbine flow and using exclusively data that was easily accessible. The models provide a rough estimate of mortality rates (M) as a function of eel size (TL), the diameter of the runner (Dr), the nominal flow rate (Q) and the rotational speed of the turbine (N).

$$M(\%) = 4.67xTL^{1.53}xDr^{-0.48}xN^{0.6}$$

$$M(\%) = 6.59xTL^{1.63}xQ^{-0.24}xN^{0.63}$$

$$M(\%) = 12.42xTL^{1.36}xQ^{-0.22}xDr^{-0.10}xN^{0.49}$$



Eel mortality rates while transiting Kaplan turbines as a function of turbine characteristics.

The consistency in the results of the three models was confirmed by running tests on approximately 60 Kaplan turbines. Use of the models depends on the availability of the data for the evaluated hydroelectric installations.

The absence of the number of blades and the head in the predictive models is due to the limited number of tests and above all to the lack of data for certain Kaplan designs. A majority of the tested turbines had four blades, very few had three, five or more blades. Also under-represented were turbines rated less than 500 kW operating with very low heads (less than 3 to 4 metres) and large turbines rated 10 to 50 MW with nominal flow rates higher than 150 m³/s and heads between 10 and 20 metres.

5. Use for operational management

Field of application. Evaluating the impact of hydroelectric installations.

Technology transfer. The available models are valid for standard Kaplan turbines currently installed in a large percentage of the existing low-head hydroelectric plants. They are not valid for fish-friendly turbines, e.g. VLH (very low head) turbines. The models may be used once the data on the turbine characteristics have been validated. For a given site, the models can estimate the mortality of that part of the silver-eel stock transiting the turbines. Other methods are available to calculate the percentage transiting the turbines.

Prospects. This work must be pursued in order to integrate the *in situ* experiments carried out for the Eel and installations R&D programme on large Kaplan and Bulb turbines installed on the Rhine (Fessenheim, Ottmarsheim) and on the Rhone (Beaucaire).

For more information…

P. GOMES, M. LARINIER., 2008. Dommages subis par les anguilles lors de leur passage au travers des turbines Kaplan. Etablissement de formules prédictives. Rapport Onema - Programme R&D Anguilles/Ouvrage, 38p et annexes.

Contact: Peggy Gomes (peggy.gomes@imft.fr or peggy.gomes@onema.fr)

Evaluating the cumulative mortality over entire river sections caused by hydroelectric installations during the downstream migration of silver eels

Responsables scientifiques :
Peggy Gomes (Onema), Michel Larinier (Onema), Philippe Baran (Onema).

Hydroelectric plant seen from downstream. © P. Gomes

1. General context of the project

Prior to implementing measures to attenuate the impact of hydroelectric installations over entire river sections, it is necessary to quantify the impact of each individual installation and of the river section. Quantification depends on in-depth knowledge of 1) the migratory conditions, 2) the distribution of the fish in the various channels through the installations and 3) the mortality rate of the fish passing through the spillways and the turbines. Projects in the R&D programme resulted in significant progress on these three aspects and made it possible to develop and apply to actual cases a method designed to evaluate survival rates over entire river sections.

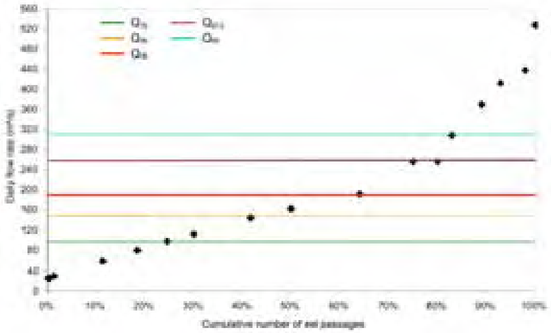
2. Goals of the project

The goals of the project were to:
- determine the various steps in a process to estimate the impact of each installation and of the entire river section;
- devise the protocols for the collection of the necessary data;
- test the method on a number of different rivers.

3. Study sites - Methods

The method used the results and assembled the models produced by programme projects to develop a set of tools to estimate quantitatively the mortality caused by a hydroelectric installation during eel downstream migration and to diagnose the overall impact of an entire river section. The tools had to be biologically relevant and be based on easily accessible data. The estimation method is based on the elements below.

- A model to estimate variations in the numbers of silver eels arriving at hydroelectric installations. The model may be based on a daily evaluation of eel numbers as a function of certain environmental parameters, e.g. weather, hydrology, turbidity, or on a more comprehensive evaluation based on ranges of characteristic river flow rates during the downstream-migration period. This second approach was preferred because it uses fairly accessible environmental data (rated-flow curves). The 562 passages through installations on the Gave de Pau river were processed to determine the percentage of eels migrating downstream for characteristic rated flows during the migratory period. The results revealed a fairly equal distribution among flow rates Q_{75}, Q_{90}, Q_{95}, $Q_{97,5}$ and Q_{99}.



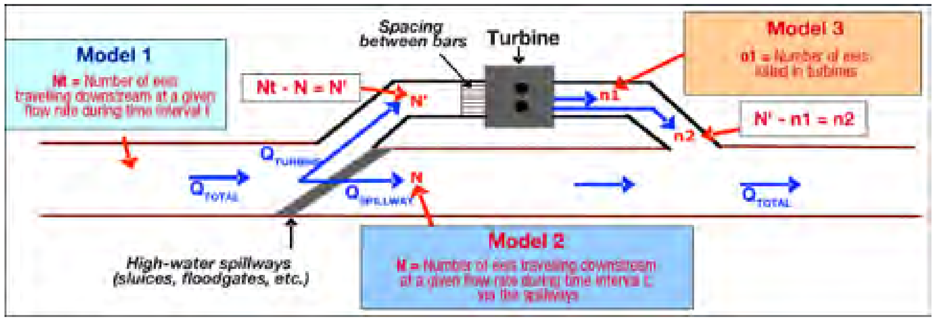
Curve of cumulative eel passages during downstream migration on the Gave de Pau river as a function of the hydrology during the migratory period.

- A model to determine eel distribution between the turbine intakes and the other channels of the hydroelectric installation. This model is the result of statistical processing (GLM) of the 476 passages on the Gave de Pau river as a function of the ratio between the spillway flow and the total river flow. The ratio is highly dependant on the turbine flow of the given installation.

- A model to estimate the potential mortality of the eels transiting the turbines. This model is based on the analysis carried out in a project which determined the links between injury/mortality rates on the one hand and eel size and turbine characteristics on the other. The analysis was based on the results of significant *in situ* experiments carried out in Europe and North America. The data from the 29 tests drawn from the scientific and technical literature served to formulate links between mortality rates, certain turbine characteristics (diameter, rotational speed and nominal flow rate) and eel size.

4. Results of the project

- Model integration



- Development procedure for the estimation method

• Step 1 - Data collection
The hydrological data were drawn from the Banque Hydro database, using the daily flow rates during the downstream-migration period of eels (this period depends on local conditions). The data were recalculated for each installation taking into account the percentage of the river basin draining to that installation. For each year that the data were available and confirmed, characteristic values of the rated flows (Q_{75}, Q_{90}, Q_{95}, $Q_{97.5}$, Q_{99}) were calculated. The information on each hydroelectric installation must be collected from the various State agencies and filled out with survey data obtained directly from the installation management.

The consistency of all the above data must be checked. Concerning eel stocks in rivers, the distribution of silver eels must be calculated on the basis of either the surface area of the river basin or the length of the river. Three representative lengths were selected, representing 15 to 30 days of work for river sections with 15 to 25 installations.

• Step 2 - Estimations for a single installation
For each installation and each annual value of the rated flows, the migrating eels assigned to a given size (model 1) were distributed between the spillways and the turbines (model 2). It is generally assumed that the eels transiting via the spillways do not suffer any notable injuries. The eels transiting the turbines were assigned a mortality rate (model 3). Survival rates were calculated for approximately a dozen years and then an average survival rate was calculated for the installation.

• Step 3 - Estimations for an entire river section
These estimations are carried out on the basis of the eels arriving upstream of each installation, either from the habitats just upstream or after transiting upstream installations, and they require five days of work for a river section comprising 15 to 20 installations.

This method provides for each year and for a given period a percentage of surviving eels for each installation and an overall percentage of eels surviving all the hydroelectric installations. The interannual variability of the survival rate may be explained by the hydrological conditions. When applied to a river in south-west France comprising **26 installations**, the model indicated an **overall survival rate between 33% and 66%, with an average of 49%.**
Recommendation. With the exception of the turbine mortality rates, the data for the method were drawn from multi-annual monitoring programmes on downstream-migrating eels covering a set of six hydroelectric installations along the Gave de Pau river (snow and rain-fed river). The characteristic periods and flow rates of downstream migration will vary in other hydrological situations and may be refined if information on downstream-migration rhythms are available locally.

5. Use for operational management

Field of application. Evaluation of the impact of hydroelectric installations on the downstream migration of silver eels.

Technology transfer. This project produced a method to estimate the cumulative impact of hydrolelectric installations along an entire river section. These estimations must be based on validated data and be checked. They may be used to compare installations and to set priorities for work to enhance the survival rates.

Partners: Departmental territorial agency of the Pyrénées-Atlantiques department, ECOGEA

For more information…

Bruno VOEGTLE, Michel LARINIER, 2008. Définition d'une stratégie de restauration de l'axe de migration pour l'anguille. Cours d'eau du Gave de Pau. Rapport ECOGEA/MIDIVAL/Onema- Programme R&D Anguilles/Ouvrage,

Contacts: Philippe Baran (philippe.baran@imft.fr ou philippe.baran@onema.fr),
Peggy Gomes (peggy.gomes@imft.fr ou peggy.gomes@onema.fr)

Predicting numbers of downstream migrating eels as a function of environmental factors and development of an operational prediction model for turbine management on the Loire river

[Datasheet 9]

Scientific director:
Anthony Acou (MNHN)

Fishing on the Loire river. © A. Accou

1. General context of the project

One possible solution to reduce the mortality of silver eels during their transit through hydroelectric turbines is to temporarily shut down the turbines. For shutdowns to be effective and manageable, they must 1) take place during peaks in migratory activity and 2) be planned at least 24 hours in advance to provide installation managers with the necessary time.

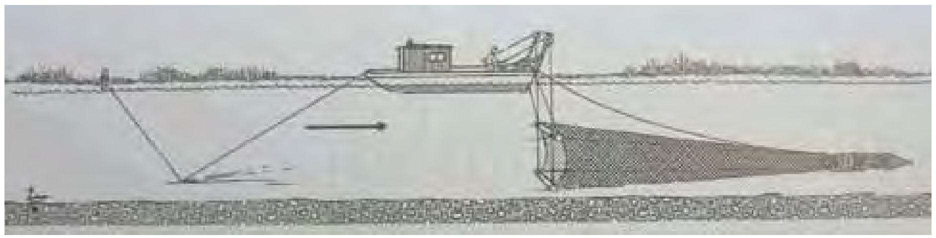
2. Goals of the project

- On the basis of a review of the literature, determine the environmental factors characterising the time windows for high migratory activity.
- Model the number of captures per unit of effort (CPUE = number of silver eels caught per night of fishing) as a function of the factors likely to influence downstream migration.
- Use the predictions produced by the model to time turbine shutdowns in a fictive hydroelectric installation located in the study zone and estimate the contribution of the model to improved turbine management.

3. Study sites - Methods

Study site. The Loire river between Angers and Nantes. This is the only site in France for which a long data series on the capture of silver eels is available due to the presence of highly organised, professional fisheries.

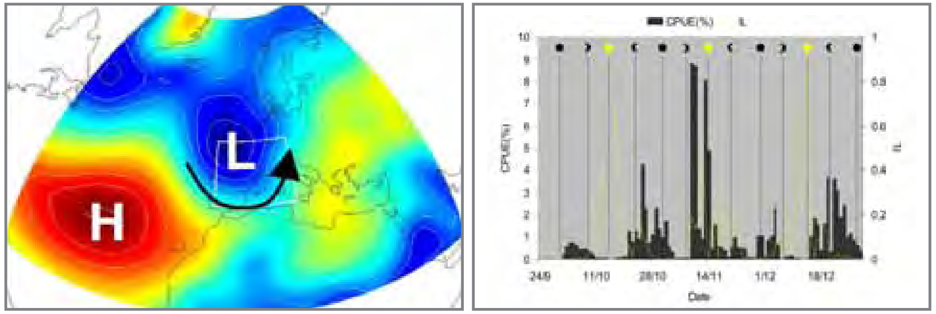
Capture data. The data series spans 20 years (1987-2006) of daily captures using «guideau» nets. The data are the averaged daily values from four fisheries. A guideau net is a special device used to catch eels during their downstream migration. It is essentially a trawler net that remains stationary in spite of the current due to an anchor and cable system.



Guideau net in position (source: Guide des engins de pêche fluviale et lacustre, CSP, 2003).

Environmental and time variables used in the model

- Daily variation in river flow rate (ΔQ, in %).
- Turbidity (TURB, in NTU = nephelometric turbidity units), which quantifies the amount of light perceived by an eel in the water column.
- Luminosity index (IL, not expressed in units; Cairns & Hooley, 2002), which quantifies the total nightly light based on the moon phases and cloud cover. The IL index varies from 0 (e.g. a new moon with heavy cloud cover) to 1 (full moon with a clear sky). In spite of a full moon, the IL index may be zero due to very heavy cloud cover (e.g. the night of 14 November 1997, see figure B below). Each night, the IL index provides a much better estimate of the light perceived by eels at the water surface than the previous system based solely on the moon phases.
- Weather situation (TEMPS, Paquet *et al.*, 2006), which describes the atmospheric conditions according to eight general parameters (central low-pressure zone, high-pressure zone, easterly winds, etc.).
- Number of the week (SEM).



A B

A. An example of weather. L and H are atmospheric low and high-pressure zones. The black arrow indicates the direction and the shape of the low-pressure weather front.
B. A graph presenting CPUE values for silver eels (1997 season) with the corresponding luminosity indices (IL) and the moon phases.

The model (delta-GLM)

- The model is the result of the fusion of a presence-absence model (logistic regression) and of a linear model simulating the relative CPUE values (daily percentages of annual captures).
- The model was cross-validated using the «Leave one out» method. This method tests model robustness by validating a data set spanning x years a total of x times, but leaving a different year out each time. In this case, for a 20-year data set, the CPUE data were processed 20 times, each time with a different set of 19 years (the training data), and the predictions were tested 20 times on the remaining year (the validation data). The purpose of this method is to work out the architecture of the final model that will be based on all 20 years of data.

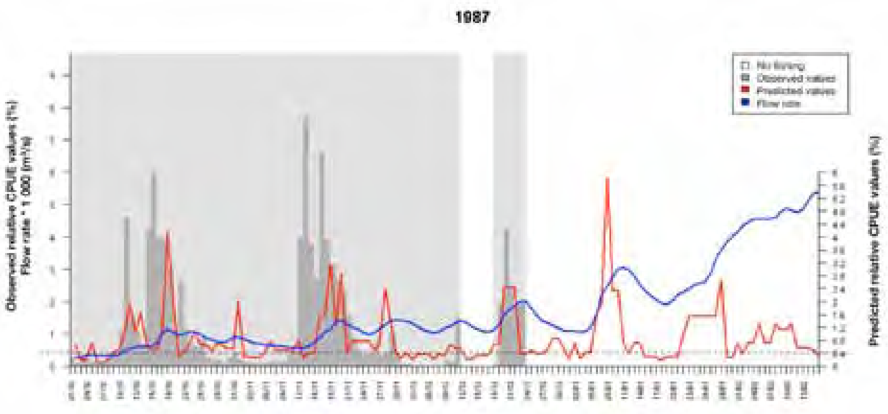
4. Résultats

- 90% of the models had the same «architecture», which would imply that they were robust in that they were not very sensitive to the training period.

$$CPUEi = IL + \Delta Q_{j-1} + TURB_{j-1} + SEM + TEMPS$$

- By introducing a lead time of one day for ΔQ and TURB, captures can be predicted 24 hours in advance.

- The final model, based on 20 years of data, predicts captures well in that approximately 80% of spikes in captures are predicted.



Graph showing relative CPUE values observed and predicted by the model for 1987.

Scenario	Criterion tripping turbine shutdown	Annual average survival rate (%, min-max) of silver eels	Annual average number of turbine shutdowns (in nights, min-max)
Turbine shutdown during entire migratory period (1 October to 31 January)	None	100	120
Hydrological scenario	Q ≥ IMF[1] (806 m³/s)	45 (0-86)	63 (0-117)
Model	***$CPUE_p$ ≥ VS high[1]*** ***$CPUE_p$ ≥ VS low[1]***	***40 (17-61)*** ***70 (40-90)***	***13 (7-25)*** ***40 (24-60)***

[1] IMF = interannual mean flow ; $CPUE_p$ = CPUE predicted by the model ; VS = $CPUE_p$ threshold tripping a turbine shutdown.

Survival of silver eels and annual average number of nights turbines were halted over the entire study period (1987-2006) as a function of various scenarios.

[Datasheet 9]

5. Use for operational management

Field of application. Limiting the impact of hydroelectric installations.

Technology transfer. Turbine shutdowns were simulated in the study zone. The results showed that if turbine management were based exclusively on flow-rate threshold values to stop the turbines (hydrological scenario), an annual average survival rate of 45% would result for silver eels and the turbines would be shut down approximately 63 nights during the season covered by the study. Use of the model, on the other hand, would considerably improve the compromise between the survival rate and the number of nights the turbines are shut down.

Prospects. This model would make possible efficient management of a fictive hydroelectric plant located in the middle section of the Loire river. The essential next steps, i.e. extrapolation of the model and testing of its predictions in other river basins (currently the Dordogne basin) are now underway. The results are important in order to adjust the model and perhaps generalise its use at some later time. In parallel, a modelling study is now in progress on smaller rivers to determine whether a smaller number of environmental parameters (variations in the flow rate, rainfall) would suffice to explain downstream-migration rhythms.

Partners: AAIPPBLB (Phillipe Boisneau), EDF (François Travade, Eric de Oliveira, Régis Thévenet), Tours University (Catherine Boisneau), National museum of natural history (Eric Feunteun)

For more information…

Acou A., Boisneau C. & Feunteun E. 2009. Prédiction des pics de dévalaison des anguilles argentées à partir des données environnementales : état des connaissances et développement d'un modèle opérationnel sur la Loire pour la gestion du turbinage. Rapport du Muséum National d'Histoire Naturelle, CRESCO, Dinard. 96 p. + annexes.

Contact: Anthony Acou (acou@mnhn.fr)

6 Cost-effective technical solutions

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The research programme invested heavily in developing and testing technical solutions to limit the impact of obstacles spanning rivers and particularly hydroelectric installations. Starting as far downstream as tide gates, tests were run on various installations to improve the passage of glass eels, similar to the manner in which brush passes were adapted to high dams. But it is above all in the field of downstream migration that the most striking innovations were produced by the research programme. Many techniques, ranging from the design of fish-friendly water intakes and behavioural barriers to fish-friendly turbines and turbine-shutdown strategies, were studied and their operational effectiveness was assessed, taking into account cost factors.

TECHNICAL-SOLUTIONS

Winter management of tide gates for eels with tests on limited admissions

[Datasheet 10]

Scientific directors:
Christian Rigaud (Irstea),
Baran Philippe (Onema).

Closed tide gate. © P. Baran

1. General context of the project

In tidal zones, a number of installations have been created to supply salt marshes located behind levees, to limit the penetration of saltwater upstream and/or to limit the regular flooding of upstream land with saltwater. Their mode of operation can hinder the free movement of young eels toward useful habitats. Given the diversity of these installations, a wide range of management solutions is desirable. In France, tests have been carried out or are now underway, thanks to associations for migratory animals (Logrami, Migado,, etc.), local entities (IAV, Brière nature park, Marais Poitevin regional park), university research teams (Rennes University, Agro Rennes), engineering firms (Ecogea, Fish Pass) and Onema research teams.

2. Objectifs de l'action

The goals of the project were to:

- analyse the available knowledge on these installations and their management with respect to eel migration, in view of developing a typology;
- evaluate the effectiveness of regularly admitting limited volumes of saltwater, by day and night, in allowing the passage of glass eels.

3. Study sites - Methods

To monitor the effects of the management technique, a study site was selected on a tributary to the lower estuary of the Charente river. The installation (Charras) comprises a double barrier with tide gates downstream and a double crest gate upstream. It is used to manage 235 square kilometres of river basin and freshwater marshes. The Charente-Maritime union of marsh managers (UNIMA) wanted to test the use of 10-centimetre wooden chocks to inhibit complete closing of one of the tide gates. Upstream, water was allowed to overflow the gate in 2010 and for half of the tests in 2011, it was allowed to flow under the gate for the other half of the tests in 2011.

Eight measurement campaigns were carried out, each comprising four successive high tides (two by day and two by night). During the 32 high tides, biological samples were taken every 20 minutes downstream and at the upstream gate to monitor the presence of the glass eels downstream and the number of fish in the water admitted upstream. The upstream and downstream water levels and the salinity levels were monitored continuously. Quantitative evaluations of suspended matter were carried out during four high tides.

The Charras installation (tide gates closed for high tide) seen from downstream. © P. Baran

*Filtering system for overflowing water.
The system was checked every 15 minutes during overflow periods. © P. Baran*

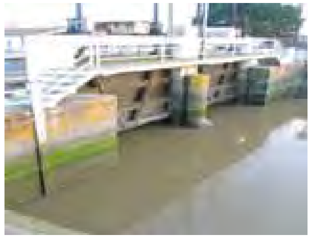
4. Results of the projects

Typology of installations

In the open estuary, the areas where salinity was higher than 5 g/l represented up to 50% of the tidal zone. The management plans for many of the installations along the estuary do not foresee the admission of saltwater (or only in very small quantities), particularly at times when freshwater is not abundant (often as early in the year as May, sometimes sooner), which reduces the capacity for dilution and the attractiveness of both the installation and a fish pass if it exists.

Tide gates and flaps opened during ebb tide. © P. Baran

Flaps to regulate water flow. © P. Baran

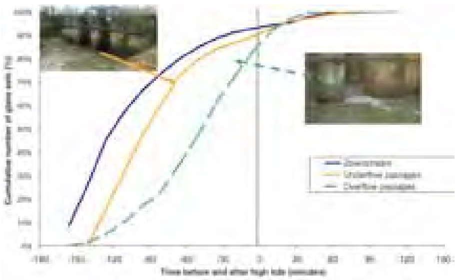


Crest gate to regulate water levels upstream. © P. Baran

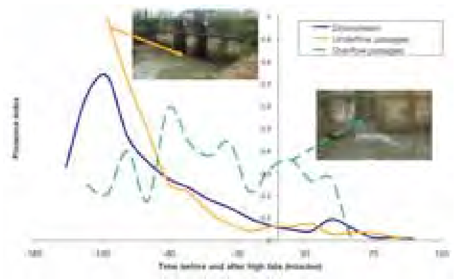
When analysing the specific case of each installation, **three major aspects** must be taken into account:
- **its position in the tidal zone** (salinity levels, position with respect to the main river);
- **its physical characteristics** (tide gates, flaps, gates upstream, special installations, etc.);
- **the characteristics of its upstream zone** that impact on the admission constraints, on the volumes of freshwater during the winter and spring, and on the quality and size of habitats.

Biological effectiveness of tide-gate winter management

A total of 52 kilograms of glass eels passed through the installation during the 32 high tides (0.8 glass eels per cubic metre of water admitted, 6 900 cubic metres of water admitted per high tide) and 70% of the passages took place at night. During underflow admissions (flap lifted 20 cm from the bottom), the tide gates almost never closed, 37% more glass eels entered than during the overflow admissions, particularly during the night, and the volumes admitted were 2.6 times greater. The passage kinetics differed, depending on the type of admission. During the underflow admissions, the number of passing eels was similar to the number of the eels arriving from downstream, with maximum numbers passing when the sea water arrived (between 150 and 110 minutes before high tide, with 75% of passages in one hour). During overflow admissions, passages were delayed approximately 30 to 60 minutes with respect to the spike in numbers arriving from downstream and were less concentrated in time (75% of passages in 90 minutes).



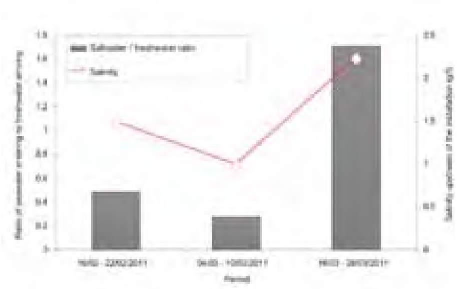
Cumulative capture curves for glass eels downstream and during underflow/overflow passages.



Presence indices for glass eels downstream and at the upstream gate, for both underflow and overflow passages.

The numbers of glass eels arriving downstream were highly variable. This variability in numbers over the migratory season would argue in favour of continuous, limited admissions, which would also encourage stable hydrological operation in the area rather than one or a small number of very short admissions of saltwater during two or three high tides over the season. Downstream migrations of glass eels were observed at the beginning of ebb tides. This is not surprising given the behaviour of the young fish in an estuary. Passage of moderate amounts of water and maintaining a sufficient water level in the upstream reach should limit this phenomenon.

Hydraulically speaking, in 50% of cases, the volumes of saltwater admitted represented 40% of the water volumes accumulating upstream of the installation during high tides, with a median increase of five centimetres in the water level of the upstream reach (7 km long and 12 m wide). The percentage of water volumes depended on the tidal coefficient, weather conditions, the management system for the installation and the upstream flow rate in the canal, which varies in winter from 0.3 m^3/s to 8 m^3/s (median value is 1 m^3/s) for a river basin covering 33 square kilometres.



Evolution de la salinité des eaux en amont des portes en fonction du débit du canal.

Concerning salinity, the values measured upstream of the installation changed in step with the tides, varying between 0.3 g/l and a maximum of 22 g/l. The values measured during low tides must still be analysed. When saltwater was not admitted, the average value was 0.7 g/l, whereas it rose to 1.7 g/l on average when saltwater was admitted.
The salinity levels in the canal at low tide depended on the freshwater flow rate. When the flow rate dropped from 1.2 m^3/s to 0.25 m^3/s, the salinity increased up to 2.2 g/l, a value three times higher than the normal level. Such a high salinity level, which occurred in April 2011, is not compatible with the upstream activities.

5. Use for operational management

Field of application. Limiting the impact of tide gates.

Technology transfer. Admitting saltwater upstream is a management technique that can be rapidly implemented, is reversible, fairly inexpensive and an effective means to ensure the passage of fish, notably during the winter season.

It is preferable that the technique be used on permanent installations allowing a limited, but regular flow that can be managed on site by human intervention. It is necessary to distinguish between three situations.

- **Installations for saltwater zones upstream.** Water may be admitted all year long. The only possible constraint lies in the risk of flooding.
- **Installations at the downstream end of freshwater zones.** Winter admissions are justified, particularly for installations where high salinity levels downstream often signal high numbers of glass eels. The risks concern the salinity and suspended matter.
- **Installations in tidal zones, but fairly far upstream.** The low salinity level of the water arriving at the installation generally makes regular admissions possible, at least until the beginning of summer.

Step 1 - Analyse the installation, its management system, the upstream and downstream situation.

- Potential for eels upstream and any problems (regular dry periods, acute pollution, etc.).
- Limitations on use of the upstream reach, in terms of the salinity, suspended matter and/or flooding. **This analysis must produce an estimate on the permissible amounts of water admitted upstream.**
- Physical characteristics of the installation and its position with respect to the tidal zone (high salinity during the winter season?).
- Management system, particularly concerning water released.

Step 2 - Sizing of the technical solution to admit seawater.

- **Tide gates.** Crest gates set to admit seawater for tidal coefficients greater than 70 and management of upstream gates, if possible implementing underflows. Crest gates with tide gates set to allow the entry of seawater as soon as it arrives or possible installation of chocks to block the total closing of the tide gates when the quantities of seawater to be admitted are not severely limited.
- **Flaps.** Element in the system making it possible to maintain a limited opening during the rising tide or to delay closing.
- **Locks.** Can be used in the winter with two phases, filling of the lock and admission upstream.

Prospects. Experiments on other sites implementing specific management techniques will be carried out to collect a maximum of information on the various geographic contexts in view of producing suitable technical solutions.

Partners: UNIMA, Charente-Maritime federation for fishing and the protection of aquatic environments

For more information…

M. LAMARQUE, C. RIGAUD, A ; ALRIC, P. BARAN, 2012. Evaluation du comportement des civelles au droit d'un ouvrage à la mer et test de la modalité de gestion hivernal. Rapport Onema/Irstea - Programme R&D Anguilles/Ouvrage.

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Christian Rigaud (Christian.Rigaud@irstea.fr)

TECHNICAL-SOLUTIONS

Test on a brush pass for eels at a high dam (Golfech on the Garonne river)

[Datasheet 11]

Scientific director:
François Travade (EDF R&D)

Brush pass with ramps and rest basins at the Golfech dam. © L. Carry

1. General context of the project

Fish passes designed specifically for glass eels and elvers are equipped with special surfaces (brushes, studs, etc.) and have low flow rates. In 2002, this type of pass was installed at the EDF Golfech hydroelectric plant on the Garonne river (17 metres of head) to compensate for the existing fish elevator that had proven ineffective for eels. From 2002 to 2007, only the lower section of the pass was built. It led to a trap basin and the eels were then transferred manually upstream. In 2008, the pass was completed to the top of the dam. Similar fish passes on high dams in New Zealand encountered the problem of eels returning downstream before reaching the summit. That is why an intermediate «cut-off basin» was installed at Golfech to avoid return travel.

2. Goals of the project

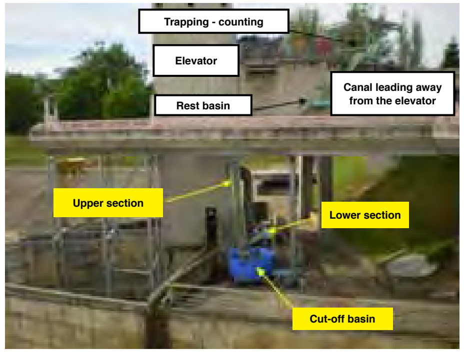
The goal of this project was to validate *in situ* the effectiveness of the complete pass.

3. Study sites - Methods

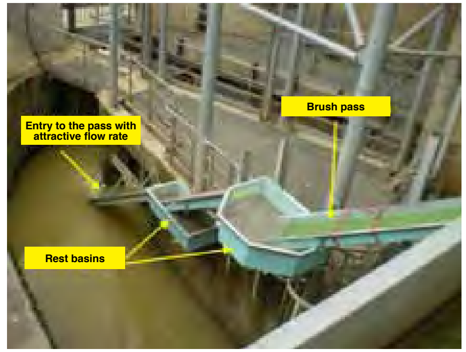
The study was conducted over three migratory seasons (May to July, 2008 to 2010) on the eel pass at the Golfech hydroelectric plant on the Garonne river. It was run by the Migado association with EDF R&D.

The eel pass is positioned next to the fish elevator at the Golfech dam. The pass is 40 metres long and is made up of a series of PVC ramps with synthetic brushes (made by the Fish Pass company) in the bottom to help the eels crawl up each section. The pass comprises two parts. The lower section (7 m vertical gain) is installed around the bottom part of the fish elevator and empties into the cut-off basin. The upper section (10 m vertical gain) climbs from the cut-off basin to the canal leading from the elevator to the river upstream. The two sections of the pass have a flow rate of 2.5 l/s. Rest basins are inserted at regular intervals. The upper section ends in a trap basin equipped with an automatic resistive counter. Three transponder data recorders were installed on the lower section, at the foot of the upper section (the exit of the cut-off basin) and at the head of the upper section respectively.

The study consisted of counting the elvers travelling through the system (trap basin and counter), checking that they did not accumulate in the cut-off basin and monitoring the progression up the ramps of individuals equipped with transponders.



Eel pass at the Golfech dam (Garonne river). Overall view. © F. Travade, EDF



Eel pass at the Golfech dam (Garonne river). View of the lower section. © F. Travade, EDF

4. Results of the project

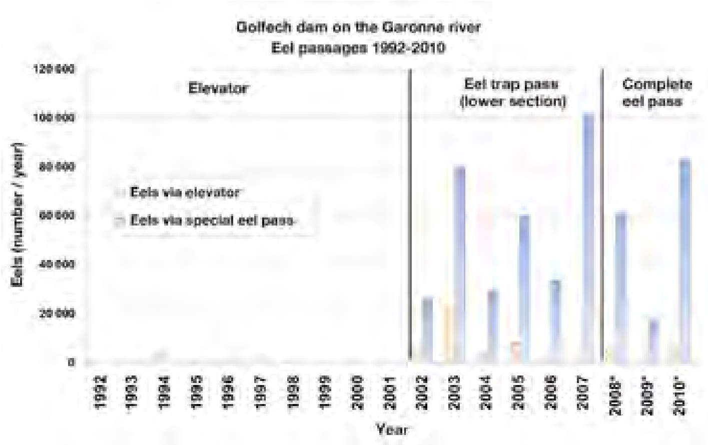
The cut-off basin installed to inhibit return travel downstream served its purpose well in that 50% of the tagged eels that started up the upper section returned to the cut-off basin (between 1 and 19 times). The time spent in the cut-off basin was relatively short, less than 40 minutes for 86% of the eels, and no «abnormal» accumulation of fish in the basin was observed.

The average time required to clear the upper section was approximately 2.5 hours, with 50% of the fish exiting in less than one hour and the maximum amount of time did not exceed 24 hours. Passages took place essentially during the night (with a spike between 22.00 and 6.00), similar to the lower section alone tested from 2003 to 2007. On the other hand, it would seem that the percentage of daytime passages is higher in the completed fish pass (25 to 54% depending on the year) than in the lower section alone (20% in 2007). This may be due to the round trips undertaken by the eels in the fish pass.

The return travel downstream may be due in part to the accumulation of eels at the head of the pass, caused by their fear of dropping off the end of the ramp. The FishPass installation was subsequently modified. A ramp sloping down was added to the final brush ramp and the accumulation of eels at the end of the pass decreased significantly.

Considerable predation by birds (herons, gulls, etc.) took place and protection of the ramps and rest basins using screens was indispensable.

The annual number of passages registered in the completed fish pass (61 300, 16 900 and 83 500 eels in 2008, 2009 and 2010 respectively) is similar to the numbers observed in the lower section alone, with alternating high and low years (see figure below), which bears witness to the effectiveness of the system.



Number of eels passing the EDF Golfech hydroelectric plant on the Garonne river from 1992 to 2010.
1992-2001: Fish elevator alone.
2002-2007: Addition of a special trap pass for eels with manual transfer to the top.
2008-2010: Completion of the special fish pass for eels.

5. Use for operational management

Brush passes may be used on high obstacles. To ensure optimum effectiveness, it is advised to install a cut-off basin in the lower section to prevent return travel. It is also recommended to facilitate exit of the eels upstream and to protect the fish against predation by birds.

Partners: MIGADO (Laurent CARRY)

For more information…

Technical note. Test of the eel pass at the Golfech dam (Garonne river). MIGADO/EDF report to be published.

Contacts: Laurent Carry (carry.migado@wanadoo.fr), François Travade (francois.travade@edf.fr)

Test on the MIGROMAT® biomonitor on River Shannon (Ireland)

Scientific directors:
Michel Larinier - (Onema), François Travade - (EDF).

MIGROMAT® biomonitor installed on River Shannon (Ireland).
© F. Travade, EDF

1. General context of the project

One possible solution to reduce the mortality of silver eels in hydroelectric turbines is to carry out preventive measures (shut down the turbines, reduce turbine flow, open gates, etc.) during downstream migration. But it is necessary to detect peak migratory periods in order to limit the time the measures are implemented. A biomonitor capable of analysing the reactions of captive eels could be a means to predict migratory periods. The German engineering firm IFAÖ (Institut für Angewandte Ökologie) has developed such a device. It is called MIGROMAT®, however its effectiveness has yet to be proven.

2. Goals of the project

The goal of this project was to validate *in situ* the effectiveness of the MIGROMAT® system. The test was carried out over two migratory seasons, 2008-2009 and 2009-2010 (from October to February) on River Shannon (Ireland), by a team from Galway University (NUIG).

3. Study sites - Methods

The MIGROMAT® biomonitor is based on the fact that silver eels held captive in basins supplied with water from the river show signs of enhanced activity (movement in the basins) during peaks in downstream migration. The MIGROMAT® system comprises two basins, each with a capacity of five cubic metres and containing approximately 30 eels tagged with transponders (see photo). Analysis of eel movements is carried out in real time by a computer connected to a detectors in each basin. When eel activity reaches a threshold seen as characteristic of a peak in downstream migration, the system automatically sends an alarm via email, predicting the coming migratory activity.

The system was installed from September 2008 to March 2010 in Killaloe on River Shannon, upstream of a fishery using 34 nets for a capture and transport operation, including eight index nets pulled up daily.

The test consisted of comparing the alarms generated by the biomonitor to the peaks in migratory activity registered by the fishery (index nets) and of calculating the percentage of the migratory stock that would have survived had the turbines been shut down overnight (18.00 - 7.00) during the alarm period. Survival rates were simulated by three models, which differed based on the time the alarm was issued. The first was the «instantaneous model», i.e. immediate shutdown of the turbines following the alarm, the second was the «12.00 model», where the turbines were shut down at 18.00 if the alarm was issued before noon, and the third was the «18.00 model, where the turbines were shut down at 18.00 if the alarm was issued between noon and 18.00.
During the two migratory seasons, the test was carried out for a continuous period of at least 60 days.

The MIGROMAT® system set up on the Killaloe site in Ireland.
© F. Travade, EDF

The Killaloe fishery on River Shannon in Ireland.
© K. McCarthy, NUIG

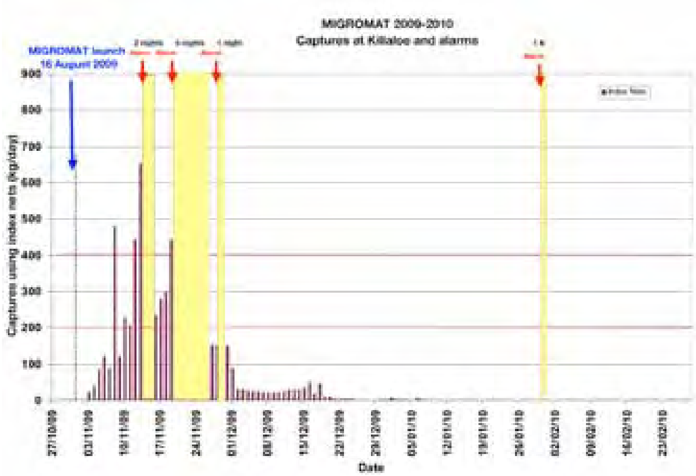
4. Results of the project

Over the two years the MIGROMAT® system was monitored, the hydraulic system (supply of river water) and the electronics (analysis of eel activity, automatic transmission of alarms, etc.) functioned very well.

The alarms issued by MIGROMAT® would have enabled the survival (depending on the three calculation models) of 14% to 21% (2008) and of 18% to 29% (2009) of the migrating stock over periods representing 2.2% to 4.4% (2008) and 5% to 8% (2009) of the total migratory period.

The limited effectiveness of the biomonitor was due essentially to the fact that detection occurred fairly late during the peak in migratory activity. MIGROMAT® succeeded in issuing alarms during the migratory peaks (see figure below), but only once the peak was well underway and occasionally several days after the start of the peak.

The eel survival rates that MIGROMAT® would have made possible (14% to 29% of the migrating stock), if it had been used to manage turbine shutdown, were insufficient in light of the survival targets set in eel-management plans, which foresee survival of 40% of the migrating stock along entire river sections.



Daily captures of silver eels in the Killaloe trap (River Shannon, Ireland) in 2009-2010 (bars) and alarms issued by MIGROMAT® (yellow zones).

5. Use for operational management

Field of application. Limiting the impact of water intakes in hydroelectric installations.

Technology transfer. Given the results to date, Onema has concluded that the MIGROMAT® system may not be certified by the regulatory authorities in France to serve as the basis for a turbine-management tool.

Partners : Galway University (NUIG), Kieran McCarthy

Pour en savoir plus :

Technical note. Final Report on the Operation of the MIGROMAT® at Killaloe, Ireland (2008-2010). Galway University.

Contacts: Kieran McCarthy (tk.mccarthy@nuigalway.ie), François Travade (francois.travade@edf.fr)

Test of an infrasonic repulsion device at two hydroelectric plants on the Gave de Pau river

[Datasheet 13]

Scientific directors:
Philippe Baran (Onema), Frédérique Bau (Irstea), Michel Larinier (Onema), François Travade (EDF).

Migromat. © D. Hauw, Onema

1. General context of the project

Silver eels risk injury or death if they pass through the turbines of hydroelectric plants. Technical solutions are implemented to limit those risks by hindering entry of the fish in the water intakes and guiding them toward bypasses. These solutions may be in the form of physical barriers (racks with small spaces between the bars) or behavioural barriers using stimuli to repulse or attract the fish (light, electricity, visual and audio means, etc.). The ProFish Technologies company has developed a system implementing infrasonic repulsion devices already used in nuclear power stations.

2. Goals of the project

The goal of the project was to test the capacity of the ProFish Technologies infrasonic repulsion system to turn silver eels migrating downstream away from the water intakes of hydroelectric plants and thus avoid their passage through the turbines.

3. Study sites - Methods

The system was tested at two hydroelectric plants on the Gave de Pau river. The plants were selected because they were high complementary. At the Biron plant, a barrier with five (2008-2009), then eight (2009-2010) repulsion devices was set up at the head of the flume. At the Baigts plant, a set of three repulsion devices was installed behind screens with a distance of 3 cm between the bars (only one campaign in 2008-2009). Immediately upstream of the plants, 150 silver eels equipped with transmitters were released and monitored by radio-telemetry via receiver stations installed at the hydroelectric plants. At each site, the itineraries taken by the fish and consequently the percentages of eels approaching and crossing the infrasonic barrier (i.e. transiting the turbines) could be determined. The effectiveness of the system was assessed by comparing the results with those obtained on the same sites during measurement campaigns in previous years. The calculation parameters included the hydrological conditions, notably the ratio between the spillway flow and the total river flow.

ProFish repulsion system installed on floats in the flume supplying the Biron hydroelectric plant. (Image © ProFish, photo © F. Travade)

4. Results of the project

In functional terms, the system turned out to be fairly fragile because over the two years that the project lasted, system interruptions and/or breakdowns required servicing 55 times on the sites. A majority of the interruptions were relatively short (a few hours).
In terms of system effectiveness, on the two sites Biron and Baigts, respectively 56% and 7% of the eels crossed the barrier and transited the turbines. The others went through the spillways (41% and 70% respectively), the fish passes (3% at Biron) and the bypasses (23% at Baigts). Some of the fish went directly through the spillways without passing in front of the water intakes. The survival of the latter cannot be attributed to the repulsion system.
At Biron, almost 80% of the fish approaching the infrasonic repulsion system crossed the barrier and went through the turbines (79% in 2008 and 78% in 2009). At Baigts, only 7% went through the turbines, but on this site, the high passage rate via the spillways may be attributed to the repulsive effect of the water-intake racks located upstream of the repulsion system as much as to the repulsion system itself. A comparison between the probability of passing via the spillways on the two sites with the infrasonic repulsion system and the results of previous campaigns without the infrasonic barrier (see the figure below) showed that the infrasonic barrier had no significant effect on the passageways used by the eels.

In conclusion, the infrasonic barriers were not successful in hindering the passage of eels via the turbines, whether in a standard site configuration such as Biron or on a less typical site such as Baigts.

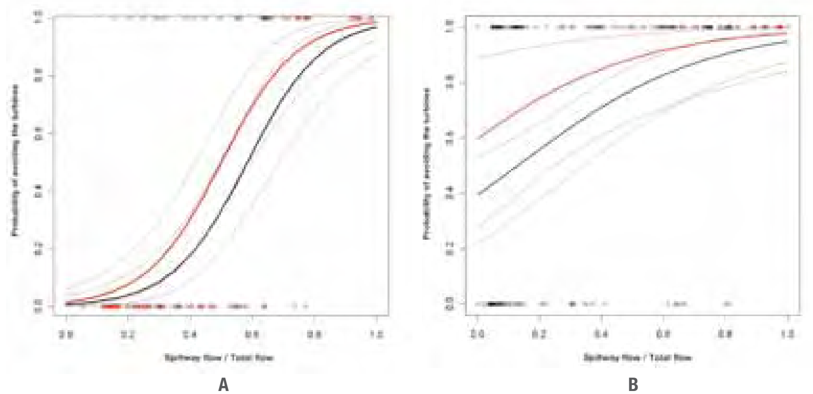


Figure 1. Average probability of eels avoiding the turbines and 95% confidence intervals (---- without the repulsion system, ---- with the repulsion system), as a function of the ratio of the spillway flow to the total flow of the river at Biron (A) and for 700 mm eels at Baigts (B).

5. Use for operational management

Field of application. Limiting the impact of water intakes in hydroelectric installations on eels migrating downstream.

Technology transfer. The results showed that the repulsion system did not significantly avoid or reduce the entry of eels into the water intakes of hydroelectric plants during their downstream migration.

Partners : CNR – EDF – Profish Technology – Topwatt company

For more information…

F. BAU, J. LAFITTE, P. BARAN, M. LARINIER F. TRAVADE, E. DE OLIVEIRA, 2011. Test d'un dispositif de répulsion à infrasons au droit de deux ouvrages hydroélectriques sur la Gave de Pau. Rapport Onema/EDF - Programme R&D Anguilles/Ouvrage, 76p et annexes.

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François Travade (francois.travade@edf.fr)

Determining the necessary conditions for fish-friendly water intakes - Head losses with inclined and angled screens, and velocity profiles just upstream

[Datasheet 14]

Scientific directors: **Laurent David (Institut P'), Ludovic Chatellier (Institut P'), Dominique Courret (Onema), Michel Larinier (Onema).**

Water intake. © D. Courret

1. General context of the project

Fish-friendly water intakes, i.e. those shielded by racks with narrow bar spacings and having one or more bypass channels to avoid the turbines, represent one type of solution to avoid or at least significantly reduce the passage of eels through the turbines during their downstream migration. In 2008, a study established the basic parameters for the design and sizing of intakes, based on feedback from experiments carried out in France and abroad (Courret et Larinier, 2008). To stop eels from entering the intakes and transiting the turbines, it is advised to use screens with 1.5 to 2 cm spaces between the bars, thus creating a physical barrier, while limiting the normal velocity perpendicular to the screen face to a maximum of 50 cm/s in order not to impinge the fish. To guide the fish toward a bypass, it is advised to use either :

- a screen set perpendicular to the flow, but inclined (low angle from the bottom of the channel), with one or more bypasses, depending on the width of the water intake, located near the top (downstream end) of the screen,
- or a vertical screen, set at an angle to the flow, with a bypass located at the downstream end of the screen. These design criteria for fish-friendly water takes imply major changes with respect to standard designs as well as consequences in terms of head losses caused by the screens and screen maintenance (raking).

2. Goals of the projectn

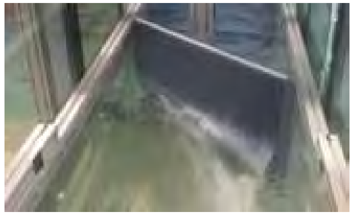
The three goals of the project were to:

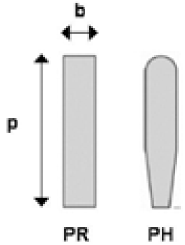
- determine the head losses incurred by screens with narrow spacings between bars in fish-friendly configurations in order to validate or adapt existing equations, or propose new equations if necessary;
- determine approach velocities to the fish-friendly screens in order to check whether the recommended design criteria produce the desired hydraulic conditions for fish migrating downstream and, if necessary, improve the design criteria;
- determine the position and flow criteria for bypasses in each configuration.

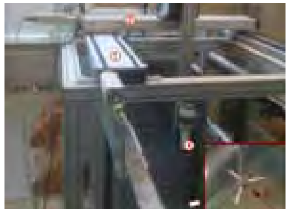
The first two goals have been met, work on the third continues.

3. Study sites - Methods

The study consisted of an experiment using a physical, scale model, first in a basin with the screen pulled through a channel, then in a hydraulic channel, custom-made for the project, at the SP2MI and CEAT sites (Institut P' in Poitiers, France). The screens were built to half scale. A total of 88 configurations were tested, combining eleven screen positions, i.e. vertical screens set to four angles β, ranging from 90° (perpendicular to the flow) to 30° and inclined screens set to seven angles α, ranging from 90° (vertical) to 15°, four sizes of spaces between the bars e ranging from 10 to 30 mm and two bar shapes (rectangular PR and hydrodynamic PH). The influence of partial screen clogging on head losses and flow velocities was also studied by adding perforated plates. Head losses were determined by measuring the differences in water levels upstream and downstream of the screen. Flow velocities were calculated using velocity profiles along the screen face acquired by an ADV device and laser measurements.



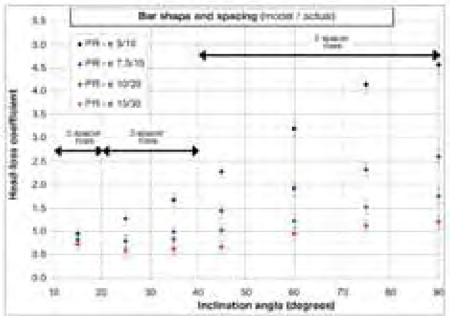


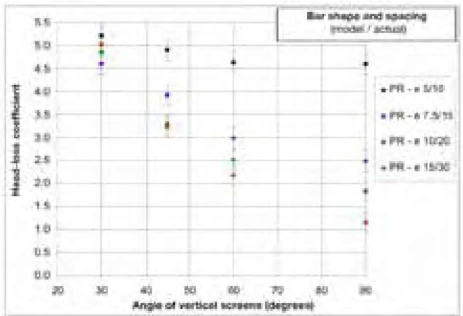


On the left, a screen angled 45°, seen from downstream, in the CEAT hydraulic channel. In the centre, the two bar shapes that were tested. On the right, the ADV 3D system with its automatic motion controller.

4. Results of the project

Head losses





Head-loss coefficients as a function of the screen inclination angle or angle to the flow, and of the bar spacing (rectangular PR bars). The arrows indicate the number of submerged spacer rows between the bars.

The equation developed by Meusburger (2002), the most complete to date, turned out not to be suitable for fish-friendly screen configurations and new equations were developed in the framework of this project. The screen blockage ratio O is defined as the ratio of the surface area of the screen elements (bars, spacers, frame) to the total submerged surface area of the screen. For screens inclined at low angles, it was necessary to differentiate between the blockage O_b due to the bars and other vertical elements, with respect to the total submerged surface area of the screen, and the blockage O_{ent} due to the spacers and other transversal elements, with respect to the cross-sectional area of the flow.

[Datasheet 14]

Head-loss equation ΔH for vertical screens set at an angle to the direction of flow

$$\Delta H = \frac{V^2}{2g} * \left[A * \left(\frac{O}{1-O} \right)^{1.6} * \left(1 + C * \left(\frac{90-\alpha}{90} \right)^{2.35} * \left(\frac{1-O}{O} \right)^{3} \right) \right]$$

Where V is the upstream flow velocity, A and C are the bar-shape coefficients representing 2.89 and 1.69 for PR and 1.70 and 2.78 for PH respectively. This equation is valid for vertical screens β = 90°) set at an angle α to the direction of flow of 30° to 90°, and applicable for blockage ratios O from 0.35 to 0.6, for bar width to bar depth ratios b / p in the vicinity of 0.125 and for bar spacing to bar width ratios e / b between 1 and 3.

Head-loss equation ΔH for inclined screens (angle from the bottom)

$$\Delta H = \frac{V^2}{2g} * \left[A * \left(\frac{O_b}{1-O_b} \right)^{1.65} * (\sin\beta)^2 + C * \left(\frac{O_{ent}}{1-O_{ent}} \right)^{0.77} \right]$$

Where V is the upstream flow velocity, A is the bar-shape coefficient representing 3.85 for PR and 2.10 for PH, and C is the shape coefficient for spacers and other transversal elements, which may be considered a drag coefficient (1.79 for cylindrical spacers). This equation is valid for screens set perpendicular to the flow (β = 90°) and inclined at an angle α from the bottom of 15° to 90°, and applicable for overall blockage ratios O from 0.35 to 0.6.

For screens set perpendicular to the flow (vertical or inclined), the effect of the hydrodynamic bars turned out to be less favourable than expected. The hydrodynamic bars reduced head losses by a factor of approximately 1.7 (whereas 2.34 was expected), compared to the rectangular bars. For screens set at an angle to the flow, the value of the hydrodynamic bars dropped in step with the angle.

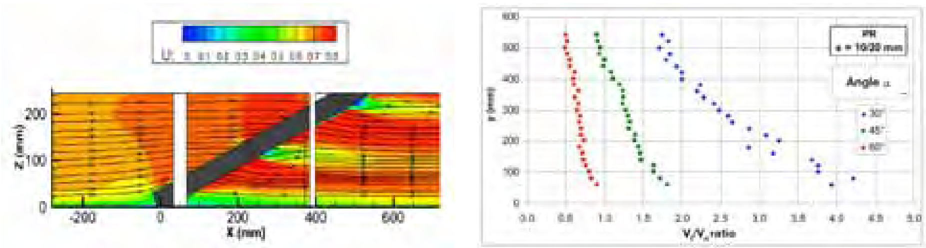
The study characterised the increases in head losses due to partial clogging of the screen, for clogging rates of up to approximately 60%. As a rough guideline, the influence of clogging may be calculated by simply adding the clogging rate to the blockage ratio.

A number of points requiring further study were identified with respect to head losses and will be addressed later in the project.

Velocity profiles

Along inclined screens, flow acceleration approaching the top remained moderate. At the top of the screen, the tangential velocities reached values approximately 20% higher than the theoretical values obtained by projecting the approach velocity (V*cos β). These values may be considered indicative of the entry velocities in the bypasses. Concerning the risk of impinging fish on the screen and in order not to create normal velocities greater than 0.5 m/s, the approach velocities for screens inclined at 15°, 25°, 35° and 45° must not exceed approximately 1.25, 0.83, 0.67 and 0.56 m/s respectively. Concerning fish guidance along the screen, the fish-friendly criterion proposed for inclination angles β ≤ 26°, in order to produce tangential velocities at least two times greater than the normal velocity and thus incite fish to rise to the surface, was confirmed.

Along angled screens, flow acceleration approaching the downstream end was significant. Normal velocities at the downstream end of the screen reached values on the order of 0.8-0.95*V, 1.0-1.15*V and 1.05-1.15*V for angles of 30°, 45° and 60° respectively. Concerning the risk of impinging fish on the screen and in order not to create normal velocities greater than 0.5 m/s, approach velocities must not exceed approximately 0.45-0.55 m/s, depending on the angle. Accepting normal velocities somewhat higher along the downstream part of the screen would make higher approach velocities V a possibility. For the entry velocities in the bypasses, values on the order of 1.7*V, 1.15*V and 0.6*V for angles of 30°, 45° and 60° respectively may be used. Concerning fish guidance along the screen, the fish-friendly criterion proposed for angles $\alpha \leq 45°$, in order to produce tangential velocities greater than or equal to the normal velocity, was confirmed.



On the left, PIV mapping of longitudinal velocities (m/s) near a screen inclined at an angle of 25°. On the right, the ratio of tangential and normal velocities along angled screens, as a function of the angle.

5. Use for operational management

Field of application. Limiting the impact of water intakes in hydroelectric installations.

Technology transfer. Design of fish-friendly water intakes. Assessment of head losses in standard and fish-friendly configurations. Head-loss equations have been developed that are suited to inclined and angled screens with narrow spacing between the bars.

Partners: CNR – SHEM – EDF – France-Hydroélectricité – ADEME – MJ2 – HYDREO

For more information…

S. RAYNAL, L. CHATELLIER, L. DAVID, D. COURRET, M. LARINIER, 2011. Définition de prises d'eau ichtyocompatibles - Perte de charge au passage des plans de grille inclinés ou orientés à faibles espacements libres entre barreaux et champs de vitesse à leur approche. Rapport Institut P' / Onema - Programme R&D Anguilles/Ouvrage.

Contacts: Laurent David (laurent.david@univ-poitiers.fr), Ludovic Chatellier (ludovic.chatellier@univ-poitiers.fr), Dominique Courret (dominique.courret@imft.fr or dominique.courret@onema.fr)

Assessment of injuries suffered by eels migrating downstream during passage through the new VLH turbine with a spherical runner housing, installed on the Moselle river

Scientific directors: **Michel Larinier (Onema), Thierry Lagarrigue (ECOGEA).**

View of the complete eel-recovery system with the VLH in operation. © Ecogea

1. General context of the project

The VLH (very low head) turbine has a number of fish-friendly characteristics that were incorporated right from the start of the design process. An initial prototype was installed in Millau and put through downstream-migration tests using smolts and silver eels in 2008. The test results were highly satisfactory and confirmed the fish-friendliness of the VLH turbine. The results also paved the way for further improvements, notably modifications in the hydrological profile. The runner housing is now spherical in order to reduce the clearance at the end of the blades. The purpose of the new tests at the Frouard hydroelectric plant was to measure the impact of the modifications on the fish-friendliness of the VLH turbine.

2. Goals of the project

One of the new VLH turbines with a spherical runner housing was installed at the Frouard plant on the Moselle river in France, in February 2010, and underwent addition tests in 2011.

3. Study sites - Methods

The Frouard hydroelectric plant on the Moselle river near Nancy lies between the Aingerey hydroelectric plant upstream and the Pompey plant downstream. The IMF (interannual mean flow) of the Moselle at Frouard is approximately 65 m^3/s (63.2 m^3/s at the Banque Hydro station in Toul, some 10 kilometres upstream of Frouard, over the 1960 to 2000 period).

The Frouard plant is in fact made up of three small, independent units. The «Moulin» unit comprises two propeller turbines, each rated for 10 m^3/s and an output of 200 kW. The «Ile» unit comprises one Kaplan turbine, wicket-gate control only, rated for 30 m^3/s and an output of 700 kW. Finally, the «Écluse» unit is equipped with the new VLH 4500 turbine that was used for the test.

The VLH turbine with a spherical runner housing has been in operation since February 2010. The turbine has eight blades and its maximum output, limited by the contract for sale of electricity, is 400 kW. The flow rate is 22 m^3/s for a net head of 2.4 metres.

Upstream of the turbine, a large plastic tube attached just above the blades of the wicket gate was used to inject the eels in the flow and, consequently, make them transit the turbine (see the photo below). Downstream, a metal frame set in grooves along the tailrace held a polyamide knotless net leading to a holding box. The box was maintained two-thirds submerged by a floating platform from which the eels could be recovered (see the photo above).

View of the injection tube connected to a strut installed on the VLH wicket gate. © Ecogea

4. Results of the project

The percentage of immediately lethal injuries for adult eels (0.6 to 1 metre long) passing through the new VLH turbine with a spherical runner housing, installed at the Frouard plant and operating at full-rated flow and power output, was very low and perhaps even equal to zero. The percentage of short-term non-lethal injuries (death not ensuing within up to 48 hours) was low, i.e. approximately 2%.

5. Use for operational management

Field of application. Limiting the impact of hydroelectric installations and developing the potential of VLH sites, including those located on rivers classified as «large-migrator rivers».

Technology transfer. A technical solution suited to low-head in-channel structures blocking rivers.

Partners: Ecogea, Onema, Ademe, France hydroélectricité, Frouard hydroelectric plant, MJ2 Technologies, EDF

For more information…

Lagarrigue, Voegtle et Lascaux, 2008. Test d'évaluation des dommages subis par les juvéniles de salmonidés et les anguilles argentées en dévalaison lors de leur transit à travers le groupe turbogénérateur VLH installé sur le Tarn à Millau. Rapport Ecogea.

Lagarrigue, Voegtle et Lascaux, 2011. Test d'évaluation des dommages subis par les juvéniles de salmonidés et les anguilles argentées en dévalaison lors de leur transit à travers le groupe turbogénérateur VLH à manteau de roue sphérique installé sur la Moselle à Frouard (54). Rapport Ecogea.

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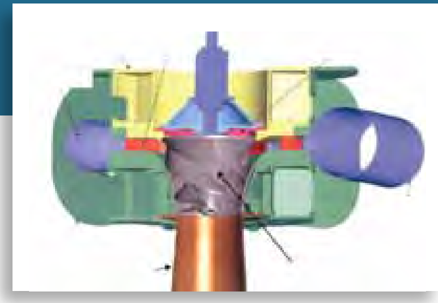
Contribution to developing the Alden fish-friendly turbine

Scientific director:
François Travade (EDF R&D)



Alden fish-friendly turbine (cross-sectional view). © EPRI

1. General context of the project

One solution to reduce injuries to fish migrating downstream and transiting hydroelectric turbines is to use turbines designed to reduce fish mortalities. A development project for this type of turbine, termed «fish-friendly» in North America, was launched in the 1990s in the United States. A new type of turbine, called the Alden turbine, was presented in 1995 by a consortium (Alden Research Laboratory and the Concepts NREC company). The design of the runner, with three helicoidal blades, was inspired by certain types of «fish pump».

The development work from 1995 to 2011 was managed by EPRI (Electric Power Research Institute) and funded by the U.S. Department of Energy (DOE) with a number of hydroelectric companies.

From 1995 to 2008, the project addressed turbine design (digital modelling) and biological tests in the lab using a 1:3.25 scale prototype.

From 2008 to 2011, the manufacturing company Voith Hydro carried out industrial-design work to optimise the energy efficiency while maintaining the fish-friendly characteristics.

2. Goals of the project

The project consisted of participating in funding the industrial-design phase of the Alden turbine. EDF contributed to funding the project managed by EPRI over three years, 2008 to 2010.

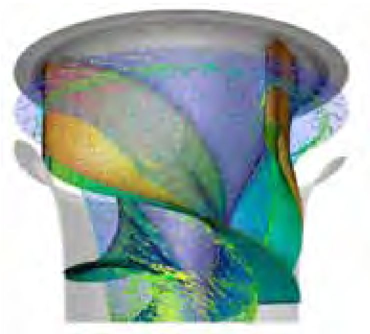
3. Study sites - Methods

The injuries suffered by fish during the transit of hydroelectric turbines have a number of causes, namely blade strikes, becoming stuck between the blades and the housing or between the blades and the runner shaft, flow shear, velocity and pressure gradients, as well as minimum absolute pressures.

By design, the Alden turbine was sized to eliminate or reduce the above causes, e.g. limiting the risk of blade strikes by reducing the number of blades (three), eliminating the risks of fish becoming stuck between the runner, the housing and the shaft by eliminating the corresponding spaces (blades welded to the shaft and to the housing which spins with the runner), limiting the pressure gradients (< 3500 kPa/sec) and maintaining the absolute pressure around the runner above 0.5 atmospheres.

[Datasheet 16]

Following the design of the runner using digital modelling techniques (see figure below), biological tests were carried out at the Alden hydraulics laboratory on a 1:3.25 scale prototype (diameter 1.22 metres, head 12 and 24 metres, 240 rpm). Approximately 40 000 fish (six species), ranging in size from 36 to 425 mm, were sent through the turbine. The survival rate of the fish, extrapolated to a full-scale turbine, was calculated at between 97 and 100%. For eels between 250 and 430 mm, the survival rate in the model turbine was 100%. However, extrapolation of the results to eels representative of the stock migrating downstream (600 to 1 000 mm) was considered too uncertain.



Digital modelling of the Alden turbine. © EPRI

4. Results of the project

Following the biological tests that were deemed satisfactory, the final design work was carried out by Voith Hydro from 2008 to 2010 with a triple goal, i.e. optimise turbine efficiency, maintain the fish-friendly characteristics and reduce manufacturing costs.
The digital modelling and the tests on the physical model (1:8.7 scale) then shifted to the industrial-design phase which produced a turbine with optimised characteristics, namely a runner diameter of 3.7 metres, a flow rate of 45 m³/s, a head of 28 metres, 120 rpm and a rated power output of 11 MW. The rated efficiency is 93.6%.

The predicted survival rate is 98.4% for fish up to 200 mm long and close to 100% for fish 100 mm long.

Biological tests run *in situ* have been programmed by EPRI on a turbine similar to the one optimised by Voith Hydro. The tests will consist of measuring survival rates for various species and lengths of fish sent through the turbine. The test sites will be selected in 2011-2012, the turbine constructed in 2013 and the biological tests run in 2014-2015.

5. Use for operational management

Field of application. Limiting the impact of hydroelectric installations

Technology transfer. The effectiveness of the Alden turbine for eels will not be confirmed until 2015, following the *in situ* biological tests carried out on fish representative of the stock migrating downstream (600 to 1 000 mm long). For equivalent head and flow characteristics, the Alden turbine has a diameter larger than existing turbines. That means it will not be possible to replace existing turbines with Alden turbines without major structural changes in installations. The Alden turbine may be used for new developments, added capacity at existing dams, minimum-flow releases and other bypass systems. Its use is theoretically possible for heads between 6 and 37 metres and for flow rates between 14 and 57 m³/s.

Partners: EPRI (Doug DIXON)

For more information…
http://www.epriturbineworkshop.com/

Contacts: Doug DIXON (ddixon@epri.com), François TRAVADE (francois.travade@edf.fr)

Part 3

Glossary and bibliography

Glossary

AIC
Akaike Index Criterion. A statistical tool to assess the relevance of a model.

ALDEN
Engineering firm specialised in fluid dynamics and the environment, based in the United States. Designer of the Alden fish-friendly turbine.

Banque Hydro
French national hydrological database. Contains the measurement data on water levels from 3 500 measurement stations on French rivers.

Bulb
Type of water turbine with a horizontal rotor. Common in French hydroelectric installations. Similar to Kaplan turbines.

Bypass
Narrow passage in a dam, located at the water surface or at the bottom of the reservoir, enabling fish to proceed downstream without passing through the turbines.

CNR
Compagnie nationale du Rhône. Hydroelectric company and a partner in the Eels & Installations R&D programme.

Conductivity
Capacity of a material or fluid to conduct an electric current (S. m-1). The inverse of conductivity is called resistivity.

Diadromous
Adjective qualifying a migratory species with life cycles alternating between sea water and freshwater.

Downstream migration
Migration through inland waters by which silver eels return to the sea.

Eel (glass)
Juvenile phase in the life cycle of European eels. During this phase, eels start their upstream migration from estuaries and the downstream areas of river basins.

Eel (silver)
Final phase in the life cycle of European eels. During this phase, eels undertake their downstream migration and journey back to the Sargasso sea.

Eel (yellow)
Middle phase in the life cycle of European eels. During this phase, most growth and colonisation of inland waters takes place.

Elver pass
Fish pass comprising rising ramps with a low flow rate, designed to provide passage for elvers to the top of a dam. The ramps are equipped with special mats that enable the fish to crawl up. There are essentially two types, brush passes and stud passes.

EPRI
Electric Power Research Institute. A non-profit research institute comprising scientists and industrial companies in the hydroelectric field, based in the United States.

FHE
France Hydroélectricité. Professional group of small hydroelectric companies and a partner in the Eels & Installations R&D programme.

Fish-friendly
Adjective qualifying a device, system or feature designed to limit negative impacts on fish. Examples are fish-friendly water intakes and fish-friendly turbines.

Flap
System designed to allow the flow of water in one direction, but to block its return.

Flow pulse
A rapid cycle of increase and decrease in the flow rate of a river.

Glass eel
See «Eel (glass)».

GLM
General linear model. Data-processing method used to link response variables to explanatory variables.

Guideau
Type of net, similar to a long sock, with a rectangular front, lowered from a boat anchored in the middle of a river. Standard equipment used by professional eel fishermen.

Head loss
In hydraulics, the energy lost by a liquid due to friction. An example is the flow of water through the screen in front of a water intake.

Institut P’
Engineering research institute studying materials, mechanics and energetics for transportation, energy and the environment, located in Poitiers, France. Partner in the Eels & Installations R&D programme.

Interannual mean flow
Average of annual mean flows in a river, at a given measurement station, over a reference period.

IUCN
International union for the conservation of nature.

Kaplan
Type of water turbine designed for high flow rates. Very common in French hydroelectric installations.

Glossary

Leptocephalus
Translucid larva of the eel, similar in shape to a willow leaf, that is carried across the North Atlantic by ocean currents from the Sargasso sea to the mouths of European rivers.

LNHE
National laboratory for hydraulics and the environment. A department of EDF R&D and a partner in the Eels & Installations R&D programme.

Logrami
Loire Grands Migrateurs. Association for the management and restocking of migratory fish in the Loire river basin. Partner in the Eels & Installations R&D programme.

Luminosity index (IL)
A value, not expressed in units, which quantifies the total nightly light based on the lunar phases and cloud cover.

Migado
Association for the management and restocking of migratory fish in the Garonne and Dordogne river basins. Partner in the Eels & Installations R&D programme.

MNHN
National museum of natural history and a partner in the Eels & Installations R&D programme.

Nebulosity index
A value, not expressed in units, between 0 and 8, which quantifies the cloud cover seen from a given measurement station.

Priority zone
Zone that has been assigned a high priority for work in the French eel-management plan. Priority zones comprise a total of 1555 identified installations, including 223 hydroelectric plants. All identified installations must be evaluated and, if necessary, modified to ensure safe passage in both directions by 2015.

Rated flow (Qx)
For a given river and measurement station, the daily mean flow is less than the rated flow Qx for x days out of 100. In standard practice, rated flows Q_{75}, Q_{90}, Q_{95}, $Q_{97.5}$ and Q_{99} are used.

RBMP
River-basin management plan, Schéma directeur d'aménagement et de gestion des eaux (SDAGE) in French. Planning document for management of water and aquatic environments, on the level of the major river basins in France. An RBMP sets the general framework for the various SBMPs within its jurisdiction. See «SBMP».

Resistivity
The factor in the resistance that takes into account the nature of the given material. Resistivity is the inverse of conductivity (see above).

RFID
Radio-frequency identification. Technique used to remotely recover data via antennas receiving the signals emitted by RFID chips or RFID transponders.

ROE
National database on river obstacles. A database created by Onema, that now lists over 60 000 obstacles to river flow (dams, locks, weirs, mills, etc.), their physical characteristics and functions, throughout France. Available at www.eaufrance.fr.

SBMP
Sub-basin management plan, Schéma d'aménagement et de gestion des eaux (SAGE) in French. Planning document for water management, on the level of a smaller river basin or of an aquifer. See «RBMP».

SHEM
Société hydroélectrique du Midi, a part of the GDF Suez group. Hydroelectric company and a partner in the Eels & Installations R&D programme.

Silver eel
See «Eel (silver)».

Tidal zone
The part of transitional areas between the most extreme high and low tides.

Tide gates
Installations on canals and rivers in tidal zones. They are made up of two vertical doors and often include a lock upstream. Their purpose is to regulate the inflow of salt water upstream.

Transponder
Automatic radio-frequency emitter, used to monitor the position of a moving object. Used in the R&D programme to monitor the movement of tagged eels. See «RFID».

Turbine flow
The flow of water transiting the turbines under normal operating conditions in a hydroelectric installation.

Upstream migration
Migration of glass eels and yellow eels from the lower to the upper sections of river basins.

VIE
Visible implant elastomer tags used in the R&D programme for capture-mark-recapture (CMR) operations.

VLH
Very low head. A fish-friendly turbine designed for very low heads. Developed by the MJ2 Technologies company and tested in the R&D programme.

Yellow eel
See «Eel (yellow)».

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This document is part of the «Meeting Recap» collection, intended for technicians and interested persons. It presents the main elements of meetings organised or co-organised by Onema.

Climate change. Impacts on aquatic environments and consequences for management (February and August 2010).

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