CHAPTER 1

FISHWAYS : BIOLOGICAL BASIS, LIMITS AND LEGAL CONSIDERATIONS

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1. MIGRATORY FISH ; SOME DEFINITIONS

Populations of fish are very closely dependent upon the characteristics of the particular aquatic habitat in which they live, and which supports all their biological functions (reproduction, nutrition, locomotion, etc.).

This dependence is most marked in migratory fish which require different environments for the main phases of their life cycle, *i.e.* spawning, production of juveniles, growth of adults and sexual maturation. Moving between one environment and another is essential for the species to survive.

There are two major groups of migratory species:

- **Potamodromous** species, whose entire life cycle is completed in freshwater, and whose reproduction and feeding zones may be separated by small or large distances.

  All species move about within the river catchment, but this migratory activity is of varying importance to the success of their life cycle. In species such as pike (*Esox lucius*), brown trout (*Salmo trutta fario*) and lake trout (*Salmo trutta trutta*), the zones that are essential for successive phases of the life cycle are very distinct and often separated by large distances. Migratory needs are strong in order to maintain healthy and successful populations. These needs are less pronounced in other species such as bleak or roach, but it is necessary nevertheless to maintain the circulation of individuals between reaches in order to avoid reproductive isolation.

- **Diadromous** species must change environments during the course of their life cycle which takes place partly in freshwater and partly in the sea, with distances of up to several thousands of kilometres between the reproduction and feeding zones.

  With each change of habitat, diadromous migrants undergo morphological and physiological changes that make them fragile. In juvenile migratory salmonids, this change is called smoltification. It allows them to adapt to the marine phase of their life.

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Two different groups can be distinguished amongst diadromous species:

- **Anadromous** species - *e.g.* Atlantic salmon (*Salmo salar*), Allis shad (*Alosa alosa*), sea lamprey (*Petromyzon marinus),* sturgeon (*Sturio sturio*) - whose reproduction takes place in freshwater and growing phase in the sea. Migration back to freshwater is for the purpose of reproduction. Anadromous species recognise their native river catchment, and return there to reproduce with a very low rate of error. This phenomenon of returning to their river of birth ("homing") depends principally on olfactory recognition of streams. Consequently, each river basin has a stock which is its own and which constitutes a unique, manageable unit.

- **Catadromous** species - *e.g.* eel (*Anguilla anguilla*) - have the reverse life cycle. Migration back to freshwater is a colonisation for trophic purposes. In the case of the European eel, the broodstock gather together in the Sargasso Sea. Isolation of broodstock from any one place or river basin does not appear to occur and therefore there is one common stock of eels for the European Atlantic seaboard.

2. OBSTRUCTIONS TO FREE MIGRATION: THE MAIN HISTORIC FACTOR IN THE DECLINE OF MIGRATORY SPECIES

A steady reduction in the geographical range of migratory fish has been observed in France over the last two centuries, a reduction that has accelerated over time until very recently.

The decline in migratory species has been particularly marked in diadromous species. In most cases, the main cause of their decline being the construction of obstructions preventing free movement. Up to now this cause has largely masked that of water pollution or over-fishing. Obstructions have been the reason for the disappearance of entire stocks (salmon in the Rhine, Seine, Garonne, etc.) or for the confinement of certain species to a very restricted section of river catchment (*e.g.* salmon in the Loire, shad in the Garonne or Rhone, etc.).

It is only very recently (during the 1970's) and thanks to improvements in, and implementation of specific technology that the trend has been reversed and that one might have considered reopening their former territories to migratory fish. This knowledge enabled restoration programmes for migratory populations to be developed.

3. THE REQUIREMENTS FOR FREE MOVEMENT

3.1 Requirements for movement vary between the species

Table I gives the biological characteristics of the principal diadromous migratory species. The reproduction zones for anadromous species are distributed throughout the river systems: upper and mid zones for salmonids, mid and lower zones for shad and lamprey. Eel tend to colonise the whole of a river catchment.

River catchments on the Atlantic coast are therefore likely to play host to different stages of one or other of the migratory species throughout their entire length.

Eel	CHARACTERISTICS OF THE LIFE CYCLE		Salmon *Salmo salar*	Sea trout *Salmo trutta*	Shad *A. alosa - A. fallax*	Lamprey *Petromyzton marinus - Lampetra fluviatilis*	Sturgeon *Acipenser Sturio*
Sargasso Sea	*Reproduction sites*	*Position of the reproduction sites*	Upper and mid zones	Upper and mid zones	Mid and lower zones	Upper and mid zones	Mid and lower zones
		Characteristics of the reproduction sites	Gravel bedded water courses	Gravel bedded water courses	Pebble bedded water courses - pelagic eggs	Gravel beds (salmon)	Deep trenches in water courses
March to July	*Date*	*Date*	November-January	November-January	May-July	*P. marinus*: March-June t° > 8-10°C *L. fluviatilis*: May-June t° > 15°C	May-June
?	*Duration of incubation*	*Duration of incubation*	Incubation + resorption approx. 3 months	Incubation + resorption approx. 3 months	Incubation: 7 days at 18°C 4 days at 22°C	Incubation: *P. marinus*: 10-13 days at 18.5°C	Incubation: 3 days at 19°C 7 days at 14°C
Assumed: 1 year	*Duration of transoceanic migration*	*Duration of life in fresh water*	1-2 years	1-2 years	3-6 months	Immature life: around 4-5 years	Approx. 6 months + several months of estuary life
In several phases in summer	*Colonisation of freshwater*	*Downstream*	March-June	March-June	Summer and autumn - Period of life in the estuary	*P. marinus*: October-February *L. fluviatilis*: October-April	Winter
3 to 10 years	*Duration of life in fresh water*	*Duration of life in the sea*	1-3 years	1 summer to 2 years	3 to 5 years	*P. marinus*: 20-31 months *L. fluviatilis*: 17-29 months	Longevity > 60 years Immature fish return to the estuary
5 to 12 years	*Minimum age for first maturity*	*Minimum age for first maturity*	Approx. 3 years	Approx. 3 years	Males: 3 years Females: 4 years	6-7 years	Approx. 10 years
Autumn and winter (peaks with the increase in flow)	*Reproductive migration period (downstream)*	*Reproductive migration period (upstream)*	Variable depending on the stocks. Several returns may cover practically the whole year	1 peak in June-July 1 peak in autumn	March-July	*P. marinus*: December-May *L. fluviatilis*: October-April	March-June
No	*Multiple spawning*	*Multiple spawning*	Rare (< 10%)	Very frequent	Rare with *A. alosa*. Very common with *A. fallax*	No	Yes
CATADROMOUS SPECIES		ANADROMOUS SPECIES					

Table I: Characteristics of the life cycle of the most common migratory species.

The restoration or maintenance of a stock of migratory fish is only possible if all suitable zones are accessible. Management strategies must take into account the nature and location of all the obstructions in the catchment, and of the species present:

- In sections of watercourses **downstream of the reproduction zones** (salmon or sea trout) it is necessary to maintain **permanent and total** free passage at all obstructions. Without exception all obstacles must be passable and the delay to migration at every obstruction should be minimised as much as possible.

- When the obstacles are located **within the middle of growth or reproduction zones,** the provision of fish passes at obstructions furthest downstream results in an immediate increase in production. Eel and shad are an illustration of this. It is equally necessary to minimise delays in passing obstacles for such species, because their active migration period is of limited duration, and for the shad, very close to the reproduction period.

- In the case of potamodromous species which have more limited migratory requirements than diadromous species, it is necessary to maintain communication between the river reaches, but the number of migrators who complete passage is less important. Careful attention must be paid to the hydraulic conditions in the fishway but a weaker level of attractivity to the fish pass is acceptable if it is intended for these species only.

3.2 Unrestricted movement is almost a permanent requirement

The overlapping migratory periods of the many species present in large rivers makes it necessary to maintain permanent passage at the obstructions. This is illustrated in Figure 1, which shows the mean monthly count of fish in the Bergerac fishway on the Dordogne. The spring peak (April-June) corresponds to the spawning migration of the shad and the passage of potamodromous species. Outside of this peak there is a continuous movement of fish, with certain species movement concentrated at particular periods (for example the peak migration of salmon and sea trout is at the end of the year, *i.e.* October to December). It should be noted that the design of the trap at Bergerac does not permit monitoring of the passage of lampreys and eels, which would increase the total number of fish recorded in spring and summer.

Taken over several years, runs in salmon rivers, may cover the whole year depending upon when the hydroclimatic conditions are favourable to migration. Figure 2 shows the mean monthly figures for salmon caught at the Kerhamon station (River Elorn, France). The pronounced peak in the months of May, June and July corresponds to the arrival of grilse (salmon which stay only briefly in the sea, characteristic of the rivers of the Armorican Massif). However, migration activity is maintained all year round, with some fluctuation in intensity.

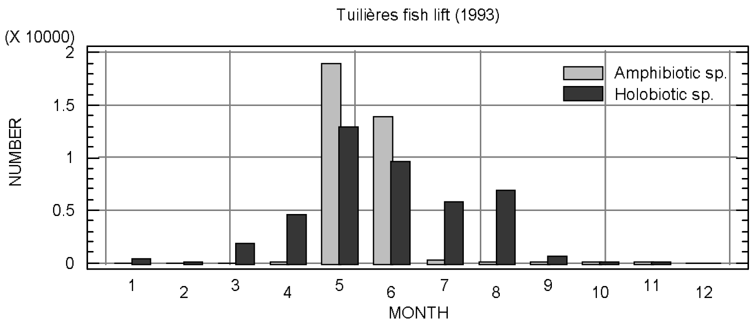

Figure 1: Monthly fish passage in the Tuilière fish lift on the Dordogne river.

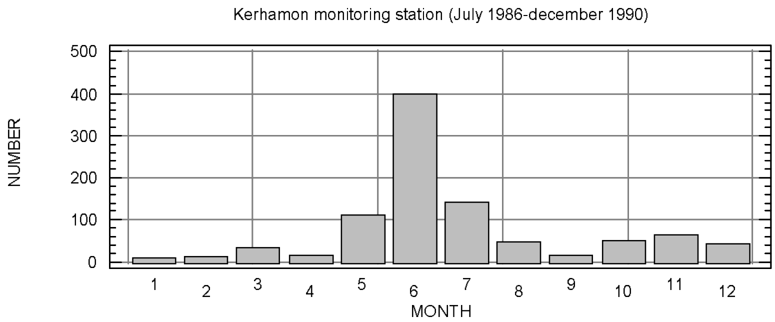

Figure 2: Monthly fish passage at Kerhamon monitoring station on the Elorn river.

Because of the wide range of species present there are only very short periods of time when fish passage is not necessary, and the fishway(s) not operated. This may occur in the upper zones of certain catchments not reached until shortly before the spawning period of salmonids, for example. However, whatever the reason may be, free passage must be guaranteed as soon as migrators do begin to arrive at an obstruction. Attempts to pass obstructions without a fishway (or with a badly designed one) can cause injuries or mortalities amongst the migrators. Observations made on elvers and small eels blocked downstream of a dam have also shown that they can suffer a high mortality rate from predators.

3.3 Unrestricted passage cannot be guaranteed for ever

Simply providing a fish passage facility does not in itself solve the problem of passage for migrants. The facility must be maintained permanently, and its effectiveness must be verified periodically, as any environmental change is capable of altering how well it functions:

- Change in upstream or downstream water levels at the obstruction as a result of channel works or instability of the river bed,

- Modification in the hydraulic management of the site (modification to the equipment, installation or removal of turbines, new operating procedures).

The failure of just one fish passage facility on the migratory route is enough to totally ruin all other concerted efforts to maintain or develop stocks.

A watercourse being developed to re-establish unrestricted passage must therefore be a watercourse that is closely and **permanently monitored**. It can no longer be regarded as a natural system and must be actively **managed**.

4. RE-ESTABLISHING FREE PASSAGE: HOW IT IS ACHIEVED, CHALLENGES, AND LIMITATIONS

4.1 Designing fishways requires skill in the fields of both biology and hydraulics

The biological requirements of migratory species are the basis for the design of fish pass facilities. The term “fish pass” conceals a diversity of situations. They should in fact be called salmonid, shad, cyprinid or eel passes. An understanding of the swimming or leaping ability of migrators, and also of their behaviour when faced with obstructions, has enabled criteria to be established for the design and size of the fish passage facilities required for some species. Those designing fishways in the future should not ignore these criteria. The design stage must take account of information regarding the site. It must also make use of the necessary skills in hydraulic and civil engineering, in order to guarantee that the facilities will work throughout the usual range of river discharge experienced during the migration season.

4.2 Providing a fish passage facility at an obstruction never compensates entirely for all the harm caused to migrators

The fact that the knowledge is available to re-establish passage for migrators does not mean that the number of dams and installations can be increased without creating problems. Firstly, some of the damage caused by an increase in installations on watercourses is irreparable as a result of submergence of spawning or production zones, modification of the physical/chemical characteristics of the water, or modification of the hydraulic regime, etc.). Secondly, the best-designed and most attractive fish passage facilities will always delay migration, and the cumulative effect of installations on a watercourse may quickly reach proportions which are incompatible with maintaining a population of migrators. This aspect is fundamental in the case of demanding species (shad), and in the case of downstream migration, which may be accompanied by mortalities as a result of passage through turbines and over spillways.

4.3 Free passage is only one aspect of the management of migratory fish stocks

Free passage is a necessary pre-requisite for the maintenance or restoration of the migratory population. While in the past, this factor was the primary cause of the decline or disappearance of certain species, it will only be one of many aspects to be taken into account in future stock management policy.

A migratory population is regulated by numerous other factors, some of which have come about in recent times:

- Degradation of water quality and modification of the natural flows of watercourses,

- Introduction or spread of diseases or parasites which affect the species concerned,

- Alteration in the quality of habitats by physical interference with the watercourses (extraction of aggregates, flood defence works), or the local environment (draining wetlands, isolation of flood plains) or the watershed,

- Development of new fisheries grounds (on salmon feeding grounds) or increased fishing effort.

A policy for the management of a stock of migratory fish can only be drawn up after careful evaluation of all these factors. It must deal with all the problems simultaneously, otherwise it may be found that one or other is limiting and may ruin efforts made elsewhere.

4.4 Fish passage facilities must be evaluated in terms of their biological and economic value and their cost

The objectives of managing obstructions to free passage are:

- Minimisation of the impact of the obstruction on the life cycle of migrators, with the aim of maintaining or increasing the stock;

- In a small number of cases, to increase the area of a fishery, provided that the extent of this exploitation is compatible with the maintenance of stock.

In each and every case, the associated benefits should be quantified and compared with the cost of the fish passage facility. Such an approach allows:

(a) The “benefit-cost” of the operation to be evaluated, which depends particularly on the location of the hydraulic plant within the distribution area of the species. While a pass at a site located downstream of all the spawning grounds is absolutely indispensable, it is not necessarily the case when some of the spawning grounds are downstream. In the latter case one must question the necessity for ensuring passage of broodstock above an obstacle when the juvenile production areas situated downstream are either not fully utilised, or else when the downstream migration of those juveniles is not accomplished without substantial mortalities.

(b) An order of priority to be defined for the scheduling of the works when many installations need to be equipped with fishways throughout catchments or sub-catchments.

(c) A choice to be made between several types of facility for the same site, each one offering a “biological benefit”, and a specific cost.

The main criteria to be taken into account are as follows:

- Potential for spawning and juvenile production upstream of the obstruction,

- If applicable, the availability and saturation level of the production zones situated downstream of an obstruction,

- Requirements for downstream migration and ability to guarantee passage downstream past an obstruction (predicted mortalities),

- Cost of fish passage facilities for upstream and downstream migration,

- Existence and cost of alternative compensation solutions (rearing and restocking, abandoning obsolete obstructions to allow breeding grounds to be recovered, etc.).

The process to be employed for migratory anadromous species is summarised in the flow chart in Figure 3.

For certain species (salmon, and to a lesser extent, sea trout), techniques are available for evaluating the different criteria and allowing a rational decision to be made:

- Estimation of production capacities based on a quantitative description of the fish habitats,

- Evaluation of the current situation by counting the number of migrating fish, redd counts on the spawning grounds, or electrofishing or other surveys of the juvenile fish population,

- Assessment of the problems for downstream migration and likely mortalities when passing through turbines or over spillways,

- Estimating the cost of the various different facilities to re-establish passage (upstream and downstream) or alternative compensating solutions.

On the other hand, the level of knowledge of other species (*e.g.* shad, lamprey) is far less advanced, and is not sufficiently well known to enable satisfactory long-term decisions to be taken.

Necessity of downstream migration

1 : Indispensable
2 : Important
3 : Advantageous
4 : Unnecessary

Species	Juveniles	Adults
Salmon	1	3
Sea trout	1	2
Lamprey	1	4
Twaite shad	1	4
Allis shad	1	2
Eel	-	1-3 (*)
Brown trout	1	1-2
Grayling	1	1-2
Pike	1-3 (**)	1-3 (**)

(*) depends on the location on the watercourse
(**) depends on the condition of the site

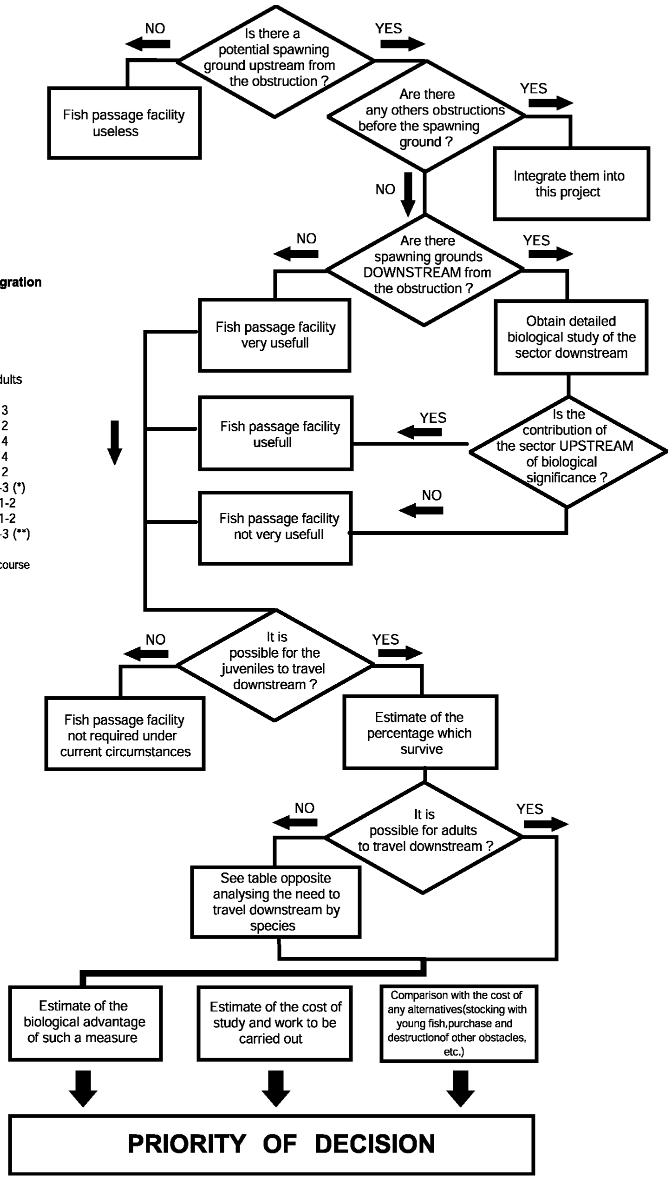

Figure 3: Flow chart for evaluating the need for a fish facility to restore fish passage for potamodromous and diadromous species

5. STATUTORY LEGISLATION

5.1 Summary

Articles L.432-5 to L.432-8 of the Environment Code (see below) specify both the obligations of licence-holders with regard to the passage of migrators, and also the punishment for infringements.

Hydro scheme licence-holders are obliged by this statute and, as a result, must always ensure:

- The continued existence, passage and reproduction of the fish in the by-passed section. The species concerned are defined as “those that inhabit the water at the time when the installation is built”.

- The inclusion of fish passage facilities at the installation in any watercourse, or part thereof, designated by national decree, for the species designated by statutory order.

There is a five-year deadline for existing installations to comply after naming of the watercourses and publication of the list of the migratory species.

The minimum flow to be maintained in the watercourses is specified by law, and maintenance of the flow is obligatory. The impact on available flow for hydroelectric plants, or implementation of measures required to satisfy the provisions of the law, cannot be considered as grounds for claiming compensation.

Finally, memoranda on the application of these texts specify:

- Firstly, that installations without existing legal status, and also these seeking renewal of licences or concessions, are classified as new developments and must fulfil the conditions defined by the law;

- Secondly, that the authorities may specify that any new fish passage facilities which they deem necessary for the migratory species already present, or else in the course of being introduced, be provided on new installations, including those on non-designated watercourses, in accordance with article L.432-6 of the Environment code.

5.2 The texts

ENVIRONMENT CODE

SECTION III:
FRESHWATER FISHING AND MANAGEMENT OF FISHERY RESOURCES

Chapter II: Preservation of aquatic environments
and protection of the national fishery heritage

Section 3
Obligations relating to hydro schemes
(formerly Part II, Section 3 of the Rural Code)

Article L.432-5 (former Article L.232-5 of the Rural Code)

Any hydro scheme to be constructed on a watercourse must include facilities to guarantee a minimum flow in the river to ensure the continued existence, passage and reproduction of the species that populate the waters at the time when the hydro is constructed. If applicable, facilities that prevent fish from entering the intake and discharge channels must also be provided.

This minimum flow may ***not be less than*** *one tenth of the mean annual daily discharge of the watercourse at the hydro scheme (evaluated on the basis of a minimum of* *five consecutive years of data), or than the flow immediately upstream of the installation, if the latter is less.*

However, for watercourses or sections of watercourses whose mean annual daily flow is greater than 80 m^3/s, the State Council may decree for each of them, a fixed minimum flow which is not less than one twentieth of the mean annual daily flow.

The operator of the hydro scheme undertakes to ensure the operation and maintenance of the facilities guaranteeing the minimum flow on the watercourse specified in the above two paragraphs.

The provisions of the above paragraphs will be extended to all hydro schemes existing on 30 June 1984, with a progressive reduction of the difference between the actual value defined in their concessions or licences and one tenth of mean annual daily flow.

The minimum flow must be increased within a period of three years, with effect from 30 June 1984, in order to reach one quarter of the levels fixed in the second and third paragraphs of this article, unless the design makes this technically impossible. The government must present parliament with an evaluation of the status of implementation of the above after five years.

The provisions will also apply immediately and in full at the renewal of concessions or licences for any installations.

The application of the provisions of this article will not constitute grounds for claiming compensation.

The provisions of this article do not apply to the Rhine or Rhone due to the international status of these two rivers.

Article L 432-6 (former Article L.232-6 of the Rural Code)

Any hydro scheme in watercourses, canals, or parts thereof in the list specified by decree must provide facilities to ensure the passage of migratory fish within six months of notification by the authorities. The operator of the hydro scheme is obliged to ensure operation and maintenance of these facilities.

Existing hydro schemes must conform with the provisions of this article within five years of publication of a list of migratory species by catchment or sub-catchment, specified by the minister responsible for freshwater fisheries, and, if applicable, by the minister responsible for maritime affairs, without compensation.

Article L.432-7 (former Article L.232-7 of the Rural Code)

Classification of the watercourses or sections thereof and canals made under the regulations governing fish ladders prior to 01 January 1986 remains valid under the first paragraph of article L.232-6.

Article L.432-8 (former Article L.232-8 of the Rural Code)

Any breach of the provisions of articles L.432-5 and L.432-6 will be liable to a fine of 1,000-80,000 Francs. If a person is sentenced under this article, the court may decide that failure to carry out the measures described under the above articles by the specified deadline will entail payment of a fine under article L.438.7.

6. EFFICIENCY OF FISH PASSAGE FACILITIES

The statutory obligation to ensure the free passage of fish gives rise to the concept of efficiency of the fish passage facilities, which is currently poorly defined. Is a fish pass which is efficient for a given species one that allows the passage of at least one individual, a defined fraction of the population, or all of the population present at the foot of an obstacle? Should the length of time that a population takes to pass the obstruction (delay in migration) be taken into account?

The definition is not simple because the concept of efficiency must be in relation to the biological requirement (or level of need) at such a facility. It therefore depends on the species concerned, the number of obstructions on the watercourses, and the location of the obstruction on the watercourse.

The objective will be to make the whole migratory population use a salmon or sea trout passage facility that is downstream of a spawning ground. If this watercourse also contains a large number of obstructions, an objective will be to minimise the time taken by the fish to use them, in order that they arrive at the spawning ground in good time. On the other hand, if this fish pass is located upstream, in the middle of the spawning grounds, its efficiency is less important.

In the case of shad, a species characterised by a very short migration period, the efficiency of the passage facility must also minimise the delay at the obstruction.

Finally, in the case of a passage facility for cyprinids, where the main biological objective is to avoid isolation of the populations between different reaches, it is not necessary to try to enable the whole population downstream of an obstruction to pass upstream. The passage facility is considered effective if it is used by a "certain number" of individuals (in "reasonable" proportion to the size of the population).

The success rate to be achieved by fish passage facilities also depends on the number of obstructions in the catchment. On a watercourse having three obstructions to fish migration, installing fishways each with an efficiency of 60% will ensure passage for one fifth of the fish that enter the river. If a watercourse has 30 obstructions, then the fish passage facilities would need to be 95% efficient to obtain the same result.

The same applies to the efficiency of downstream fish passage facilities intended to minimise mortalities in juveniles when passing turbines or spillways. Where a certain percentage of mortality per obstruction is considered to be biologically acceptable in a watercourse, a downstream fish passage facility must be all the more efficient the higher the potential mortality rate in the turbines. For example, if an average mortality rate of 10% per hydro scheme is acceptable, and the transit mortality rate at power station A is 20%, the downstream fish passage facilities must be 50% effective. The downstream fish passage facilities for power station B, which has a transit mortality rate of 60%, must therefore be 83% effective.

Furthermore, in order to limit damage to within a given maximum mortality rate for a whole river catchment, the efficiency required of the downstream fish passage facilities must increase in proportion to the number of obstructions.

Generally, the potential impact of a fish passage facility on the population of migratory fish is greater, and therefore more critical, the further downstream it is located. Particular attention must therefore be paid to the efficiency of fish passage facilities in the lower reaches of the watercourse, both for upstream and downstream migration.

In conclusion, the level of efficiency to be achieved at a given site must be specified in relation to biological objectives based on research, and not as an absolute. It will therefore be fixed by taking into account the position of the fish passage facility in the catchment, the capacity to ensure upstream or downstream migration, and the impact of other obstructions. The objectives that are defined for the catchment as a whole may only be achieved through concerted action by both the operators of the installation, and by those managing the fish populations.