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FEEDBACK ON FOUR FISHPASS INSTALLATIONS RECENTLY BUILT ON TWO RIVERS IN SOUTHWEST FRANCE

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ABSTRACT

In the framework of various projects for the protection and restocking of migratory fish launched in France in the Seventies, four relatively large fishpasses were built between 1984 and 1989 on the Garonne and Dordogne rivers in southwest France (mean annual discharge between 200 m^3/s and 500 m^3/s, depending on the site). Two are pool-type fishpasses (one with a double vertical slot at Bergerac on the Dordogne river, and the other with a single vertical slot at Le Bazacle on the Garonne river) ; the other two are fish lifts (Golfech on the Garonne river and Tuilières on the Dordogne river). The size of the installations (costing between 9 and 23 millions French francs) and the discharge chosen for each (around 5 m^3/s for each installation) are on a scale with the size of the rivers in question. This paper describes the characteristics of the installation and the operating constraints involved for each type.
Since their construction, their operation has been monitored, on more or less constant basis depending on the site, using a semi-automated video counting device, which provides very precise data on the rythm of fish passage.
The two types of passes have enabled passage of some thirty fish species, including migratory diadromous species as salmon (*Salmo salar*), sea trout (*Salmo trutta trutta*), shad (*Alosa alosa*), eel (*Anguilla anguilla*), sea lamprey (*Petromyzon marinus*)... and a number of so-called « sedentary » species as roach (*Rutilus rutilus*), bream (*Abramis brama*), barbel (*Barbus barbus*) for which very clear migration rhythms have been nonetheless observed. Passage of shad, which has often been difficult over traditional fishpasses, has been found satisfactory in both these type of installations : annual passage of several tens of thousand of individuals (80,000 to 86,000 shad at the Tuilières and Golfech fish lifts in 1995). The relative effectiveness of each type of pass is discussed in relation to the various migratory species. Finally, the main results with respect to migration rhythms of various diadroumous and riverine species on a seasonal and daily scale are presented.

1. INTRODUCTION

In view of the decline in migratory fish populations in France since the end of the 19th century, programs to restock the main species were initiated by the government in the Seventies. One aspect of the restoration programs involved facilitating passage over obstacles. From 1985 to 1989, EDF, with technical collaboration from CEMAGREF and CSP, built several fish passes over hydroelectric dams on the Garonne and Dordogne rivers in southwest France. The most abundant migratory species at the time of their construction was shad, commercially fished both in rivers and in estuaries. This paper presents feedback on several years of experience with four of these passes : one fish elevator (Golfech on the Garonne), one combined elevator - pool-type fishway (Tuilières on the Dordogne), one pool-type fishway with two vertical slots (Bergerac on the Dordogne) and another with one vertical slot (Le Bazacle on the Garonne). These passes were biologically monitored and, in certain cases, fish passage has been continuously counted for several years. In addition to information on the dynamics and efficiency of the passes, the biological monitoring provided data on displacement of several species, both diadromous and sedentary.

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2. THE HYDROELECTRIC INSTALLATIONS AND FISH PASSES

2.1. Golfech

The Golfech hydroelectric installation, built in 1971, is located on the Garonne near Agen, some 200 km from the ocean (Fig.1). It consists in a dam that by-passes some fifteen kilometers of the Garonne and supplies the plant (three bulb wheels turbining 540 m3/s) through a 10-km headrace canal;. Turbined discharge is restituted to the Garonne through a 2-km tail race. Mean annual discharge in the Garonne at Golfech is close to 500 m3/s. Head at the plant is 17 meters in low-water periods. Water level varies upstream by about 1 meter during normal plant operation, and downstream by 2.6 m between the low-water level and the level corresponding to discharge in the Garonne of 1000 m3/s, considered to be the threshold for fish passage.

Two Borland fish locks were installed at the dam when it was built, but proved to be ineffective due to their poor design and the preference of migrants for the area near the plant, given the low discharge (10 to 20 m3/s) in the bypassed section of the Garonne. A new device was therefore built beside the powerhouse in 1987: a fish elevator designed along the lines of that at Holyoke on the Connecticut river (Dalley, 1980 ; Travade et al., 1992). This type of device was preferred to a pool-type fishway due to the need to ensure passage of shad (*Alosa alosa*).

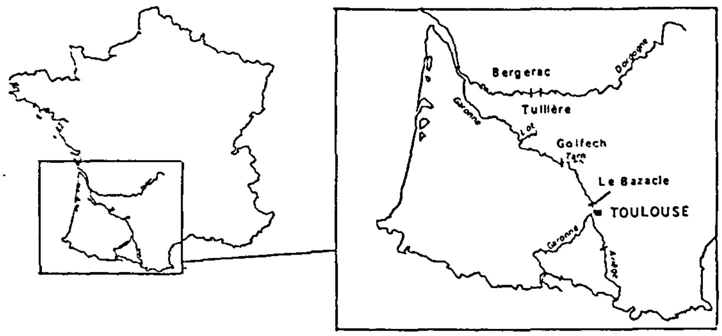


Figure 1 : Location of the fish facilities

The fish elevator was found at the time, in cases of high obstacles, to be the most efficient for American shad (*Alosa sapidissima*) : the migrants are attracted by an auxiliary flow into a holding pool where they are trapped. At regular intervals, a mobile vertical screen pushes them over a tank on the far upstream side of the holding pool. The tank is then raised and emptied upstream of the plant.

The Golfech elevator is located on the right bank of the tail race, some twenty meters downstream of the turbine gates. From downstream to upstream, it consists in (Fig.2) :
- the entrance, 1.7 meters wide with an automated gate which enables keeping a constant difference in level between the holding pool and the downstream reach,
- the holding pool 9 m long, 2.5 m wide and varying in depth from 1.5 to 4.5 m depending on discharge in the Garonne, with, in the upstream part, a ditch (2.5 x 2.5 x 2 m) containing the tank. The mobile screen in the pool both traps the fish and concentrates them above the tank. It is composed of two panels of screens (1.5 x 4.5 m) with horizontal bars 2.5 cm apart. It is displaced by a jackscrew and a hydraulic winch which respectively close the trap and translate the mobile screen.
- a concrete tower 26 m in height for maneuvering the 3.3-m3 tank. Fish are spilled out through an automated flap in the lower part of the tank.
- the upstream transfer canal, 250 m long, 2 m wide and 2.5 m deep through which fish pass into the headrace canal. A maximum discharge of 1 m3/s ensures sufficient velocities to encourage migrants to continue upstream (0.3 m/s $< V <$ 0.6 m/s).

Discharge in the pass (maximum 5 m3/s) is gravitationally drawn from the upstream reach through an automated flap. After passing through baffles to dissipate energy, it is injected into the holding pool through vertical screens (bars 2.5 cm apart) upstream of the tank and on the side walls. The installation is entirely automated. Several parameters (frequency for raising the tank, discharge, head at the entrance, velocity in the transfer canal) can be adjusted by the operator. The minimum period between two cycles is 10 minutes. A station for visual counting of fish through a glass window is located on the upstream transfer canal. The cost of construction in 1987 was 23 million French francs.

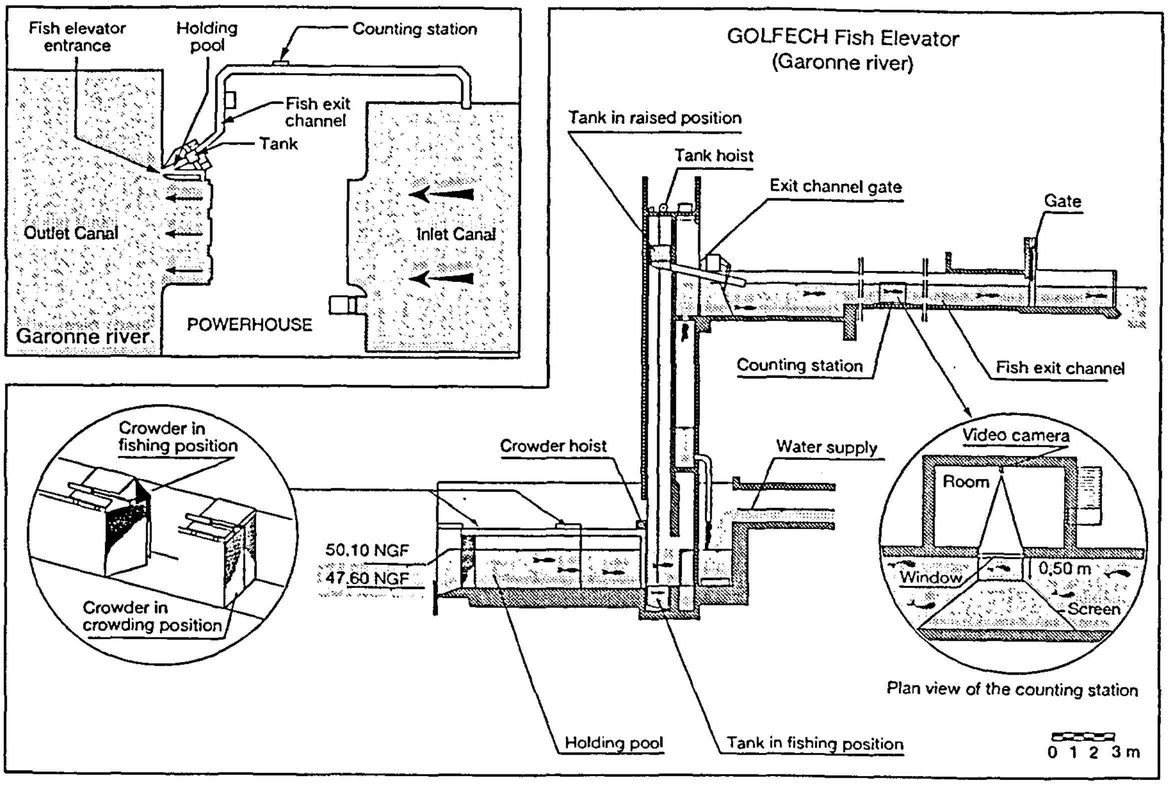


Figure 2 : Golfech fish elevator

2.2. Le Bazacle

Le Bazacle is located in Toulouse some 300 km from the ocean, and is the first obstacle encountered on the Garonne upstream of the Golfech plant. It consists in a weir 270 m long and 4.5 m high, and a power plant on the right bank with 7 turbine sets, giving turbined discharge of 86 m3/s. Mean discharge of the Garonne in Toulouse is around 180 m3/s. The upstream migration installation built in 1989 comprises two passes with the same water intake (Fig. 3):

- a pool-type fishway with a vertical slot in the plant, with the entrance near the turbine gates. It measures 67 m in length and consists in 16 pools 3.7 m long, 2.5 m wide and from 1.6 to 3 m deep, and one larger downstream pool into which auxiliary flow is injected through a vertical screen. The pools communicate through vertical slots 0.4 m wide. The entrance to the pass (downstream) is 2 m wide and has a submerged gate which serves to ensure constant head at the entrance. Head between pools is 0.3 m and energy dissipation in the pools between 170 and 200 W/m3. Discharge into the fishway varies according to that in the river, from 3 m^3/s during low-water periods (1 m3/s in the pools and 2 m3/s of auxiliary flow) to 5 m^3/s when discharge in the Garonne is at 600 m^3/s (1.7 m^3/s in the pools and 3.2 m^3/s of auxiliary flow). Discharge in the fishway is from 6 to 7% of turbined discharge.
- a Denil fishpass between the dam and the power station, 56 m long and 1.8 m wide. On the downstream side, it has a regulating section and three ramps (slope : 17%) separated by two resting pools. Discharge is between 0.6 m^3/s and 1 m^3/s.

The passes are designed for discharge in the Garonne ranging from 30 m^3/s to 600 m^3/s, corresponding to a variation in level of 1 m upstream and 1.45 m downstream of the dam. A fish counting station with two underwater windows, one to monitor the Denil fishpass and the other the pool-type fishway, is located in the upstream part of the pass. The cost of construction in 1989 was 9 million French francs.

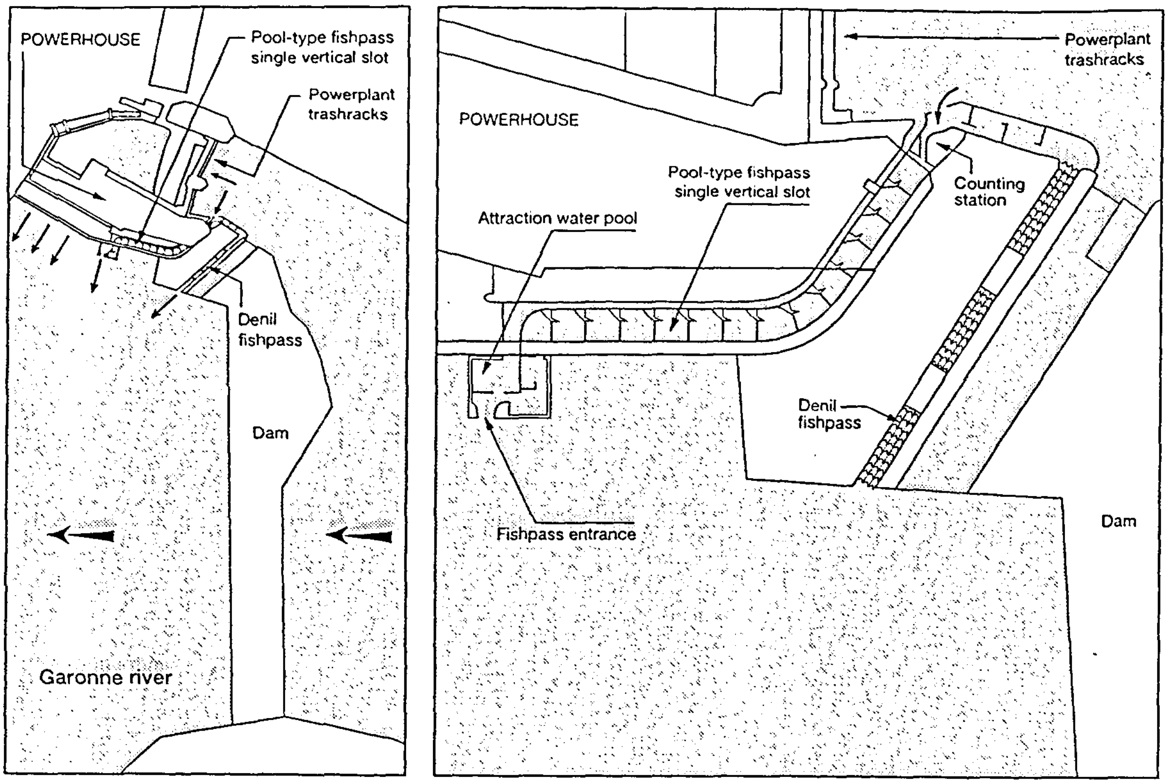


Figure 3 : Le Bazacle dam and fishpasses

2.3. Bergerac

The Bergerac installation is located on the Dordogne some 100 km from the sea and consists in a dam 165 m long and 4.2 m high, on the right bank of which is the power plant, designed for discharge of 57 m3/s. Mean discharge in the Dordogne is around 265 m3/s in Bergerac. Low-water discharge is around 30 m3/s.

Several fish passes have been installed by the dam since its construction in 1847. All proved to be ineffective, either because they were undersized or because they were poorly suited to certain species such as shad. The new installation opened in 1985 (Larinier et Trivellato, 1987) is a pool-type fishway with double vertical slots, on the right bank of the dam near the power plant (Fig. 4). It measures 73 m in length and comprises 13 pools 4.5 m long, 6 m wide and from 2 to 7 m deep. Slots between the pools are 0.55 m wide. In the larger downstream pool, auxiliary flow is injected through a vertical screen; this pool communicates with the downstream river reach through an entrance 2 m wide with a gate to maintain constant drop between the pool and the downstream river segment. The difference in level between pools is 0.3 m and dissipated energy in the pools 150 W/m3. Discharge in the pass varies with upstream level from 2.5 m3/s to 13 m3/s: 2.5 to 7 m3/s in the pools and 0 to 6 m3/s of auxiliary flow.

The dimensions of the pass are designed for discharge in the Dordogne ranging from 30 to 1000 m3/s, corresponding to respective variations in level upstream and downstream of the dam of close to 3 m and 5 m. A trapping device for counting fish passing through the pass is located in an intermediate pool. The cost of construction in 1985 was 10 million French francs.

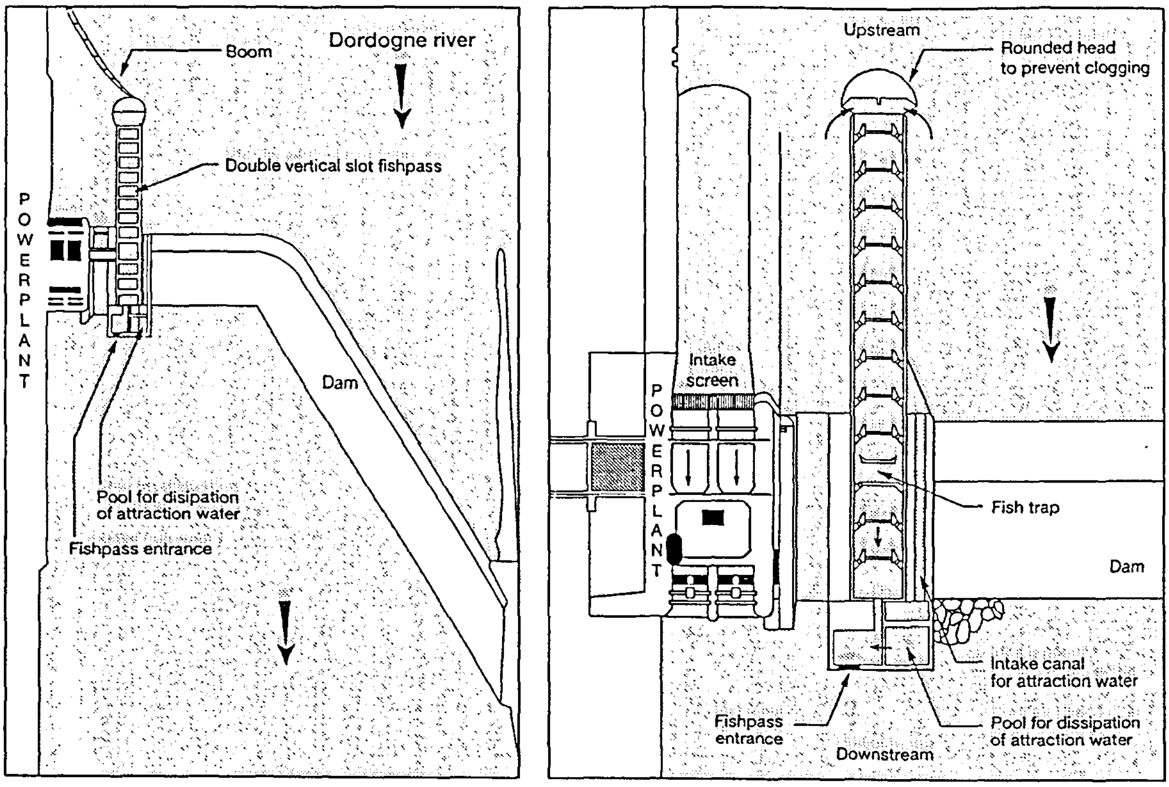


Figure 4 : Bergerac weir and fishpasses

2.4. Tuilières

The Tuilières installation some 120 km from the mouth of the river (around twenty km upstream of Bergerac) consists in a dam/plant complex some 150 m long, creating a head of 12.5 m. The 100-m dam is of the weir type (8 Stoney gates); the plant, on the right bank, has 8 Kaplan turbines providing total discharge of 420 m3/s.

A pool-type fishway was installed by the dam on its construction in 1902. It was transformed into a Denil fishpass in the Fifties. Both these passes by the dam on the left bank proved to be ineffective for several reasons: low attraction due to the low discharge on this bank in relation to the turbined discharge and insufficient discharge in the pass; inappropriateness to species such as shad.

The new installation built in 1989 is located near the powerhouse on the right bank (Fig. 5). It is a combined fish facility consisting of a fish elevator in the lower part to overcome a 10.5-m rise, and above this a pool-type fishway (2.1-m difference in level) into which the elevator tank spills.

The fish elevator functions identically to the Golfech elevator described above. From downstream to upstream it comprises an entrance 2 m wide with an underwater gate, a holding pool (6.7 m long, 2.5 m wide and a minimum low-water depth of 2.5 m) with trapping and concentration screens on a mobile crowder, and a 3-m3 tank. The tank is raised in a concrete tower and spilled at regular intervals (40 min. to 2 hours depending on the season) into the downstream section of the pool-type fishway. Attraction water (maximum 5 m3/s) is injected through fine-mesh vertical screens (2.5 cm between bars) upstream of the tank and on the walls of the holding pool. The elevator is designed for discharge in the Dordogne ranging from 30 to 1000 m3/s. Auxiliary flow is from 1% to 5% of the turbined discharge, depending on discharge in the river.

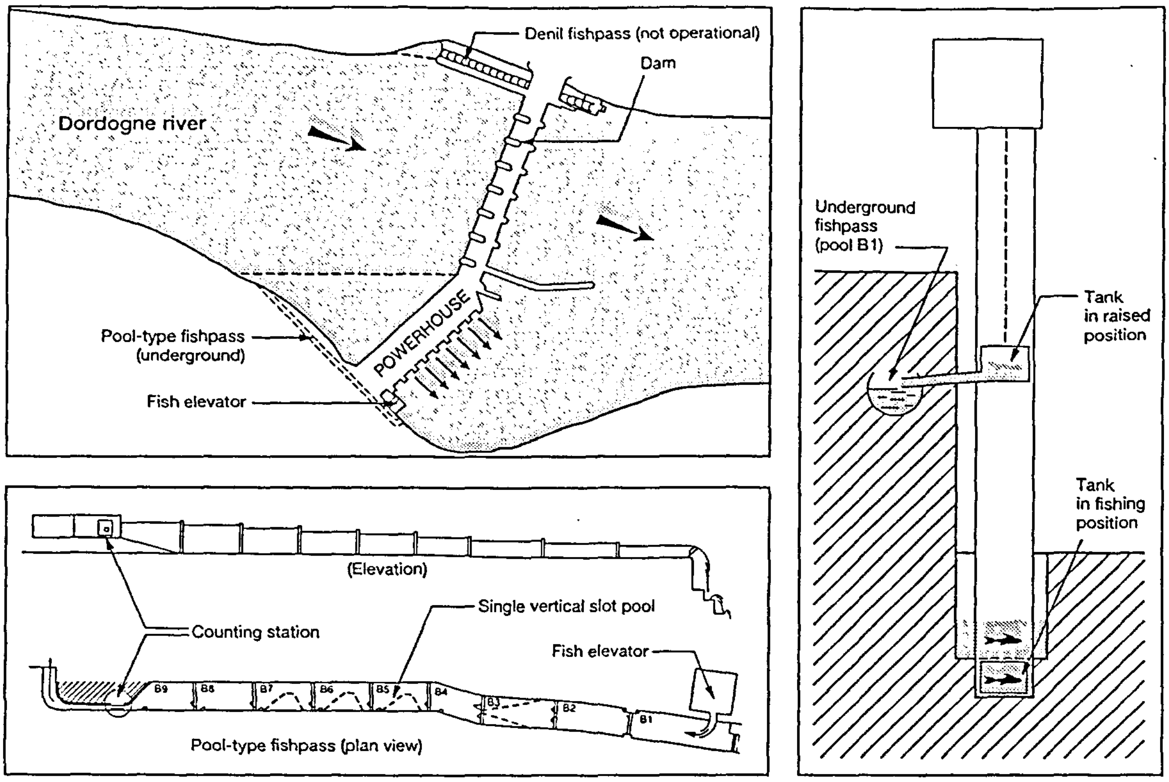


Figure 5 : Tuilières dam and fish elevator

The 70-m pool-type fishway was set up in a former underwater discharge canal with its outlet some fifty meters upstream of the plant. It consists in 9 pools, three of which in the downstream part are circular (3 m in diameter) in section and 7.8 m long, and six in the upstream part, rectangular (5.8 m long and 3 m wide). The pools communicate via a central opening for the 3 downstream pools and a vertical slot 0.40 m wide for the upstream pools. Head difference between pools is 0.3 m. Discharge in the pass is 0.6 m3/s; it is restituted downstream of the pass through a screen which prevents downstream migration.

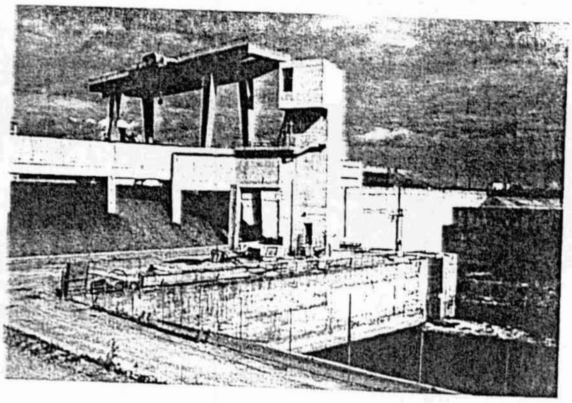
Fish are counted through an underwater window in the upper part of the pass, 1.5 m in width and 2 m in height. Cost of construction in 1985 was 10 million French francs.

3. MONITORING THE INSTALLATIONS

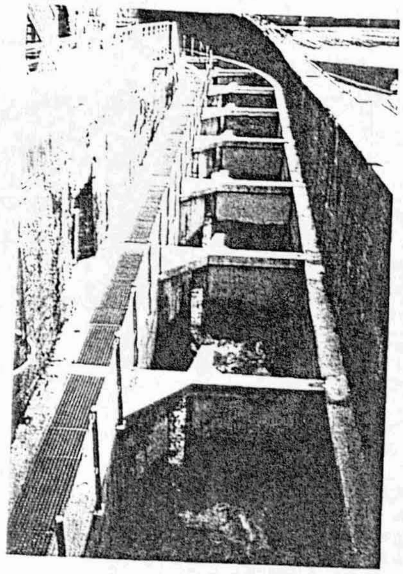
When they were put into service, all four installations were monitored to test and optimize the hydraulic, mechanical and biological characteristics.

The hydraulic and mechanical checks consisted in daily or twice-daily recording, and adjustment if needed, of various parameters likely to influence the biological functionoing of the passes : head difference at the entrance to the pass and between pools, rate of auxiliary flow, plugging up and blockage by drifting objects and, specifically for the elevators, the operating parameters of the various phases in the cycle and the frequency for raising the tank, etc.

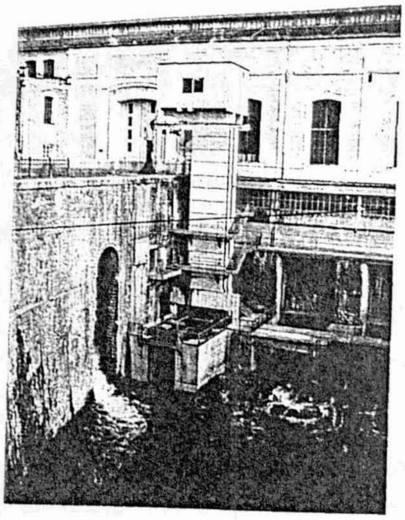
The biological checks consisted in counting the various migratory species passing through the installation, observing their behavior both at the entrance and inside, periodically analyzing their behavior downstream of the installation (visual observation) and quantifying mortality (elevators).



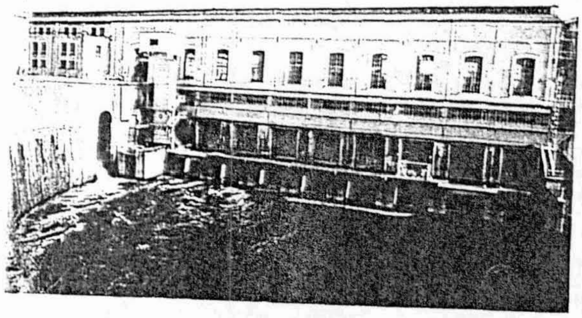
Golfech elevator



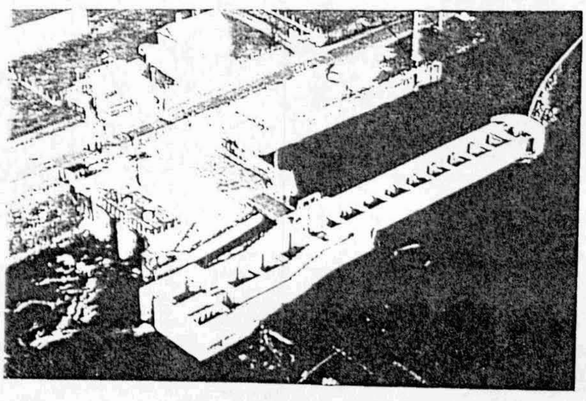
Le Bazacle fishpass

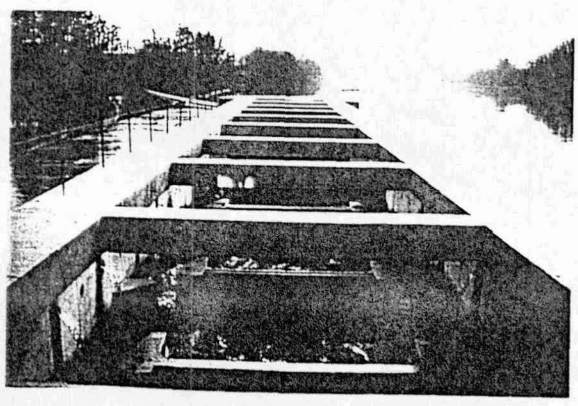


Tuilières fish elevator



Tuilières powerhouse





Two vertical slots fishpass at Bergerac weir

In 3 of the 4 installations, fish were counted as they passed in front of an underwater window, the lateral view allowing for differentiation of species. The counting stations have a glass window around 1.5 m wide and 2 m high overlooking a confinement restricting fish passage (baffles or narrowing of the structure) with a maximum width of 40 to 50 cm. The counting area is lit, to guarantee optimum visibility at all times of the day. To avoid the presence of staff at all times in front of the windows and facilitate counting, an automated recording device was perfected (CERBERE system, Travade, 1990). Its principle is to detect the arrival of fish in front of the window with an image analyzer coupled to a video camera, and to set off a video recorder. In this way, only sequences of fish passage are recorded, and can later be analyzed by an operator. This system enables continuous counting.

In the Bergerac pass, because of the difficulty of installing and operating a visual counting station, a trap was installed in one of the pools modified for the purpose. It consists in mobile screens which deflect the fish toward a chamber whose bottom contains a tank. When the tank is raised, fish are manually sorted and released upstream of the pass. Counting in this way proved to be complex, particularly during shad migration (May to July) when it was necessary to check the trap four to eight times a day to prevent mortality due to overdensity.

Counting of fish is complemented by periodic or continuous measurement (data acquisition units) of parameters likely to influence migration: water temperature, turbidity (transparency of a Secchi disk), river discharge, turbined discharge.

Monitoring of the installations was carried out initially by EDF (two to three years after entry into service) in spring-fall (May to July and October to December), the periods corresponding to passage of the main migratory species. The Golfech, Tuilières and Le Bazacle passes were then chosen to be continuously monitored for the past several years by MIGADO. This paper uses the datas published by EDF, ENSAT and MIGADO in the different annual fish passage reports.

4. FEEDBACK ON THE INSTALLATIONS

Maintaining the adequate discharge in the pass is the most problematic element in installations with high discharge, due to the risks of plugging up of openings between pools, and even more of the auxiliary flow inlets. Discharge must be injected through screens, and it proved necessary to fit both fishways with systems for protection (floating boom in the upstream outlet of the Bergerac pass, baffle on the auxiliary flow inlet), filtering (fine-mesh screens over the auxiliary flow inlet) and automatic screening. Despite such protections, regular cleaning is required mainly on elevators where there are several fixed and mobile screens. Because of this, isolating gates for the purpose of draining the passes are indispensable.

Because of their mechanical nature, elevators require regular checks and adjustment, and are more frequently unavailable due to breakdown than are pool-type fishways. Golfech and Tuilieres elevators are regularly monitored (on a daily or weekly basis) to check mechanical functions, particularly during the period of shad migration when continuous monitoring is needed to limit the risk of mortality in the case of breakdown. Maintenance of mechanical and electromechanical elements (winches, gates, screens, data acquisition units) must be carried out several times a year. Depending on the year, these constraints generate from 10 to 45 man-days' labor per year and a cost of between 5,000 and 30,000 French francs. Since the entry into service of the Golfech and Tuilières elevators, they have been unavailable for 2 to 9% of the time, due to breakdown (1 to 3% of the time) or maintenance (1.5 to 5% of the time).

Contrary to the upstream migration devices installed without success in the past on all four sites, the present installations were located in front of the powerhouse, where migrants are naturally attracted. This proved to be satisfactory, as did locating the entrances in the vicinity of the turbine outlets. Discharge in the passes, chosen in relation to that of the river (1 to 5%) (Larinier, 1983), proved to be that needed to attract migrants, as was shown by drops in frequency of passage when discharge accidentally dropped. On medium-sized rivers like the Garonne and the Dordogne, discharge in the passes must therefore be several cubic meters per second. While the installations were found to be satisfactory, their efficiency is far from optimum: it is certain that placing one or several additional entrance(s) on three of the four sites (Golfech, Tuilières and Le Bazacle) would have improved efficiency, particularly for shad. Experience shows that for this species, the efficiency of the entrance is linked to operation of the different turbines, and in some cases, the rate of turbining is changed to accelerate passage of migrants in peak periods.

It was found to be indispensable to maintain head difference at the entrance to the pass to create a velocity attractive to migrants. For shad, the optimum head difference is close to 25 cm, whereas for eel, 5 cm seems preferable. Given the variations in level in the river, gates are therefore essential at the entrance to the pass, to make it attractive.

Design and operating criteria for elevators were optimized for shad, the most problematic species given their abundance and sensitivity. It was confirmed that tank volume needs to be equal to at least 10 liters per fish in peak migration periods as used for American shad (Dalley 1980, Rizzo 1986). Tanks (3.5 m3) were raised in 1994 and 1995 at Golfech containing 300 to 400 shad (or from 9 to 11 liters per fish) with no massive mortality, though there was non-negligible loss of scales. Velocities in front of the entrance to the v-shaped trap, needed to encourage fish to enter the holding pool, are on the order of 0.6 to 1 m3/s, and the opening of the trap entrance, preventing fish from returning downstream while not preventing their entrance, is on the order of 0.4 m. When the elevator spills into a transfer canal upstream (as at Golfech), velocity must be at least 20 to 25 cm/s, below which the behavior of the principal migratory species is disturbed. The length of the cycle must be dependent on the abundance of fish: during peak shad migration, it must be on the order of ten minutes, while the rest of the year, periods of 1 to 2 hours are sufficient. Elevators inevitably pose risks of injury and mortality, due to maneuvering of the tank and the various screens. Non-negligible mortality of shad and lamprey (up to 6% for shad) was observed on entry into service of the elevators, especially at Tuilières. With the appropriate modifications (flaps on moving parts and additional screens on water inlets, etc.), mortality was reduced to 0.5 to 1%, a value close to that found for American shad at the Holyoke elevator (Rizzo, personal comm.).

5. BIOLOGICAL RESULTS

5.1. Overall conclusions on fish passage

Generally speaking, the four installations can be considered efficient for the species (shad, lamprey, salmon, sea trout) for which they were designed. In addition, at each installation, several tens of thousands of individuals, belonging to over twenty species, are observed each year.

Shad, recognized as being a species which has difficulty in overcoming obstacles due to its specific behavior, do pass on all four sites, as was never the case with the previously installed passes on these same sites. This is the most abundant migratory species, with annual passage of up to several tens of thousands of individuals: respectively 86,000, 78,000 and 21,000 in 1995 over the Golfech and Tuilières elevators and through the Le Bazacle pass, and probably more than 100,000 through the Bergerac pass.

Sea lamprey passage varies considerably from one year to another: from a few individuals to several thousand. The least passage is at Le Bazacle (a few dozen individuals per year, with a maximum of 650 in 1993). This may be due to the location of the obstacle, at the upper limit of the migration in the river.

Migratory Salmonidae (Atlantic salmon and sea trout), whose populations are being restocked, are still limited in number (a few dozen to a few hundred individuals). In both cases, an increase in migrating populations has been observed, however: from 50 to 100 individuals (total Salmonidae) from 1987 to 1992 to 250 and 640 in 1994 at Golfech and Tuilières respectively.

Eel (present at all four sites in the form of small individuals ranging from 20 to 30 cm) account for a few thousand to a few tens of thousands individuals in the Bergerac, Tuilières and Golfech passes, and only a few dozen individuals at Le Bazacle. These figures are underestimated on all sites, particularly at Golfech where the counting device is not adapted for this species, and at Bergerac, where the trap captures only a small fraction of the population. It is likely that several hundred thousand individuals a year migrate through the Bergerac pass, given visual observations in the pools and at the foot of Tuilières dam, upstream of Bergerac. The reason for the low numbers of migrants found at Le Bazacle will be discussed later.

Among the other so-called non-migratory species passing through the installations (12 to 20 species depending on the site), the Cyprinidae are the most abundant, with several tens of thousands of individuals, primarily bleak, barbel, bream and roach, which have clearly defined migration periods.

5.2. Comparison of installations

It is difficult to compare the efficiency of the different installations, given that determining the species passing through depends on the sensitivity of the counting devices, which is unequal from one pass to the other, and that migratory populations may be qualitatively and quantitatively different from one site to another. We must therefore compare not only on the basis of counting in the passes but also on the basis of qualitative information, such as the abundance of certain species observed upstream and downstream of the installations, or their behavior in the passes. The list of species observed in each of the passes is given in Table 1.

COMMON NAME	SCIENTIFIC NAME	BERGERAC 1985 1986 27 species	TUILIERES 1989 1995 26 species	GOLFECH 1987 1995 25 species	LE BAZACLE 1989 1995 20 species
		MIGRATORY SPECIES			
allis shad	*Alosa alosa*	2000- >78000 (1	2000-78000	14000-86000	1000-21000
eel	*Anguilla anguilla*	?- >19000 (1)	3000-19000	200-30000 (2)	0-30
sea lamprey	*Petromyzon marinus*	?- >6700 (1)	40-6700	15-2000	0-650
mullet	*Mugil capito*	7- >120 (1)	10-120	400-9600	
atlantic salmon	*Salmo salar (a)*	23- >332 (1)	3-332	1-134	0-55
sea trout	*Salmo trutta trutta (b)*	50- >305 (1)	40-305	4-109	3-54
indet. salmonids	(a) or (b)		0-61	1-32	0-8
		RIVERINE SPECIES			
bleak	*Alburnus alburnus*	6000-15000	15000-56000	300-110000	200-103000
barbel	*Barbus barbus*	1200-2100	800-8600	1000-4200	1300-28000
large mouth bass	*Micropterus salmoides*	0-8	0-50	2-74	0-1
bitterling	*Rhodeus amarus*	0-1	?	?	?
bream	*Abramis brama*	1170-1180	600-22000	4000-11200	200-2600
silver bream	*Blicca björkna*	180-270	presence (4)	presence (4)	presence (4)
pike	*Esox lucius*	5-14	2-28	1-7	
crucian carp	*Carassius carassius*	0-1	7-900	1-800	?
carp	*Cyprinus carpio*	0-1	3-15	1-50	4-18
bullhead	*Cottus gobio*	2-4	?	?	?
chub	*Leuciscus cephalus*	5-10	10-50	3-400	1-92
roach	*Rutilus rutilus*	700-1900	900-5700	presence (4)	1-4200
gudgeon	*Gobio gobio*	0-1	?	?	?
perch	*Perca fluviatilis*	37-42	70-890	0-10	
pumkinseed	*Lepomis gibbosus*	0-1	8-36	presence (4)	?
catfish	*Ictalurus melas*		10-1040	10-3500	0-1
rudd	*Scardinus erythrophtalmus*	presence (4)	presence (4)	presence (4)	presence (4)
pike-perch	*Stizostedion lucioperca*		9-380	20-900	
wels	*Silurus glanis*	(3)	0-16	0-2	0-1
tench	*Tinca tinca*	7-13	5-50	0-2	0-2
toxostome	*Chondrostoma toxostoma*	175-280	presence (4)	presence (4)	presence (4)
brown trout / rainbow	*Salmo trutta fario & Oncorhynchu*	4-6	40-240	10-30	0-5
dace	*Leuciscus leuciscus*	80-210	20-700	presence (4)	

[hatched] : missing species
(1) : maximum related to passages into Tuilieres' fishlift located upstream Bergerac
(2) : numbers underestimated. Counting device not operationnal for eel
(3) : species not present on Garonne and Dordogne rivers in 1985-86
(4) : silver bream counted with bream, rudd with roach and toxostome with dace

Table 1 : Fish passage at Tuilière and Golfech fish elevators and at Le Bazacle and Bergerac fishpasses

If we look at the number of species found in the passes, we find similar diversity in the Bergerac pass and at the Tuilières and Golfech elevators (25 to 27 species), and lesser diversity (20 species) at Le Bazacle. This is partially due to the fact that certain species are difficult to identify by means of video recordings because of their resemblance to other species (silver bream, crucian carp, rudd, etc.) or their small size (pumpkinseed, etc.). Other species, trapped and inventoried at Bergerac, are found in very small numbers and must be considered to be random visitors (bullhead, gudgeon, bitterling, etc.).

All species are found in the elevators. This is easily explained by the absence of difficulty in passing through the installation since, after crossing the head at the entrance, they are forced upstream.

Elevators nonetheless have only limited efficiency for small species, particularly eel. Given the observations of abundant eel downstream of Golfech and Tuilières, we can assume that only a few percent, or tenths of a per cent, of the migrating population actually pass the elevators. This is inherent to the nature of the installation: because of the mesh size of the screens, greater than the size of the small eels, only individuals swimming above the tank when it is raised are captured. This conclusion is corroborated by observations of accumulations of eels in the trapping device. However, reducing mesh size to capture small species would inevitably lead to insoluble problems of maintenance.

The double vertical slot pass (Bergerac) appear very efficient for all species, as is confirmed by observation of many small fish (bleak, etc.) in the pools and the abundance of shad and eel at the foot of Tuilières dam. Only pike-perch, found downstream, is not inventoried in the pass. The passage in 1995 of close to 80,000 shad over the Tuilières elevator would appear to represent only a fraction of the population having passed through Bergerac, given the considerable numbers found in front of the plant. The same is true for eel, for which we can estimate the population present upstream of Bergerac at several hundred thousand individuals.

The Le Bazacle pass, of the same type but with a single slot, nevertheless seems less efficient for small species, and more selective. This difference in efficiency can be explained by several factors, the most important of which is no doubt the higher turbulence at Le Bazacle than at Bergerac (200 W/m3 compared with 150 W/m3). The pool-type fishway upstream of the Tuilières elevator, even less turbulent than the preceding ones (50 to 70 W/m3), allows for passage of pike-perch which are not found at Le Bazacle and Bergerac, though head between pools is the same, 30 cm. For shad, it is important to prevent recirculation areas in the pools where they tend to gather. To avoid blockage of shad in the pass upstream of the Tuilières elevator where some pools have recirculations areas, screens had to be installed to prevent their access.

6. MIGRATORY CHARACTERISTICS OF THE PRINCIPAL SPECIES

6.1. Seasonal rhythms

Globally speaking for all species, whether migratory or not, we find, in terms of both numbers of individuals and specific diversity (mean daily number of species inventoried) (Fig. 6), clearly greater frequency of passage in spring and summer: maximum abundance is found in May-June, while diversity is maximum in June-July for indigenous species and in May-June-July for migratory species.

The diadromous migrants arrive at the monitored sites at a specific moment in the year, from May to July, like the shad whose recorded rhythms are described later; Salmonidae also migrate in fall, from September to December.

Riverine species, not subject to the same constraints as species coming from the sea, show more varied rhythms, more closely linked to environmental constraints. While the majority, and Cyprinidae in particular, prefer to migrate in spring, from May to July like the barbel, others like roach have two periods, in spring and in fall, and certain carnivorus fish like pike-perch and perch have some residual activity in summer, thus in some years having three displacement periods: end of winter, spring-summer and fall.

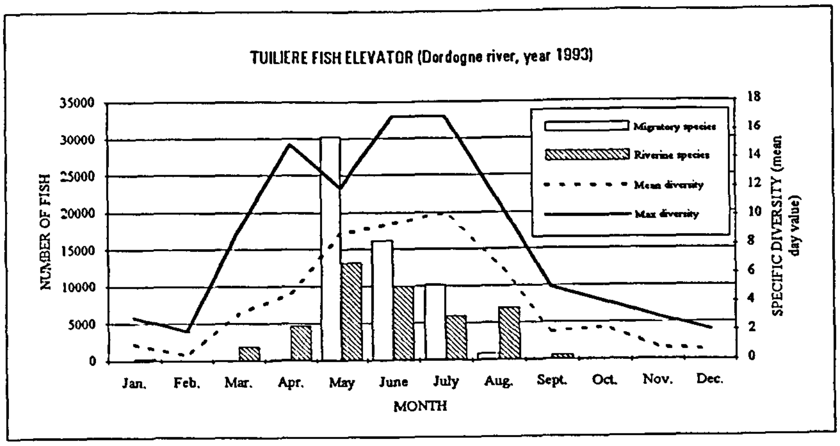


Figure 6 : Monthly fish passage and specific diversity

In addition to the biological necessity linked to reproduction, these two preferential displacement periods correspond, in environmental terms, to a warming of the water at the end of winter, and to cooling at the end of summer; this represents, in both cases, a return to temperatures favorable to normal activity for all species.

6.2. Details on the migratory activity of certain species

6.2.1. Diadromous migrants

For shad, the numbers recorded in the past decade fluctuate from a few thousand to a few tens of thousands (Table 2). These numbers vary with the distance from the site to the estuary, the number of obstacles found downstream and the type of fishpass. Numbers have been on the rise in recent years on both rivers, with variations from one year to another, no doubt related to recruitment, but also to the environmental conditions at the time of their arrival in the estuary and their migration up the river, in particular to temperature and discharge.

YEAR	GARONNE RIVER														DORDOGNE RIVER						
	GOLFECH FISH ELEVATOR							BAZACLE FISHPASS							TUILIERE FISH ELEVATOR						
		DAILY MAXIMUN				HOURLY MAXIMUN			DAILY MAXIMUN				HOURLY MAXIMUN			DAILY MAXIMUN				HOURLY MAXIMUN	
	TOTAL	DAY	TEMP.	TOTAL	%	TOTAL	%	TOTAL	DAY	TEMP.	TOTAL	%	TOTAL	%	TOTAL	DAY	TEMP.	TOTAL	%	TOTAL	%
1987	18224	Jun 05	17.3	3800	20.9	675	47.8														
1988	13779	Mai-26	15.4	1700	12.3	161	9.4														
1989	66401	Jun-12	20.3	4500	6.8			12953	Jun-22	23.3	3753	29.0	1033	27	7789	Jun-12	19	1026	13.2		
1990	43000	Jun-30	23.5	5900	13.7			14440	Jun-27	18.5	2068	14.3	443	43	4943	Jun-14	19.9	1058	21.4	218	20.5
1991	40074	Jun-22	18.5	3400	8.5			6715	Jul 02	18.1	900	13.4	170	18.8	6053	Jun-01	22.2	905	15.0	148	16.3
1992	20007	Mai-26	19.6	2378	11.9	351	14.76	1155	Mai-26	16.3	267	23.1	54	20.2	1945	Mai-29	21.2	368	18.8	53	14
1993	18554	Jun 07	20.5	1500	8.1	203	15.03	3765	Jun-08	18.5	752	20.0	135	17.9	35704	Mai-31	16.9	2783	7.8	251	9
1994	85813	Mai-24	17.2	8196	9.6	838	11.86	8010	Jun-18	19.3	998	12.5	98	9.8	62592	Jun-01	17.1	5090	8.1	396	8
1995	85624	Mai-11	18.7	7700	9.0	1308	16.99	20546	Jun-20	19.3	3008	14.6	247	8.2	78245	Mai-10	16.1	8413	10.8	873	10.3

Table 2 : Annual passages and maximum of daily and hourly shad passages on Garonne and Dordogne rivers

For sites closest to the estuary like Golfech on the Garonne and Tuilières on the Dordogne, the first individuals are observed in the second half of April (Fig. 7), whereas at Le Bazacle, 80 km upstream of Golfech, the first passages are never observed before the first week in May (the earliest year being 1992). Most migrants (25% to 75%) pass Golfech, Bergerac and Tuilières between April 30 and June 10, and arrive at Le Bazacle between May 28 and July 8, some 2 to 4 weeks after Golfech, depending on the year (Fig. 8).

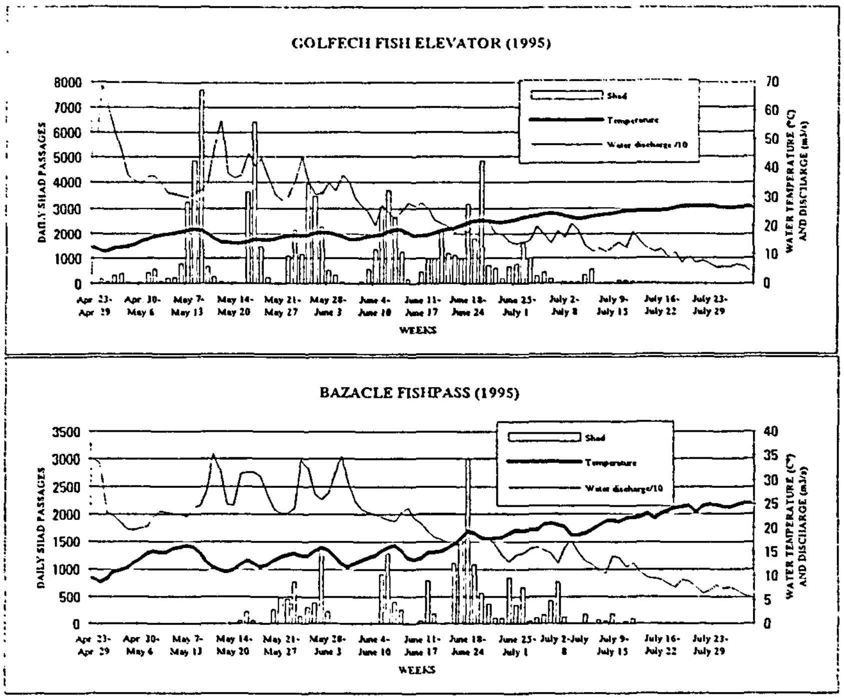


Figure 7 : Seasonal activity of shad at Golfech fish elevator and Bazacle fish pass with water temperature (°C) and river discharge (m^3/s) (Garonne river, 1995)

Migration follows characteristic patterns, with several waves giving daily peaks of from 8% to 20% of the yearly migrant stock in the Golfech and Tuilières fish elevators and from 12% to 30% at the Bazacle fishpass. This can represent daily maxima of 8,400 shad, or close to 11% of all migrants in a single day (Tuilières in 1995). These peaks are highly dependent on thermal variations in the river, as observed before the construction of the elevator (Belaud *et al*, 1985).

Daily activity is also characteristic with, on all sites, a unimodal diurnal curve (6 a.m.-10 p.m.) at its maximum between 6 p.m. and 7 p.m. These hourly maxima can reach between 8 and 20% of the daily total, representing between 1 and 2% of the total annual migration. The hourly maximum observed was 1,300 individuals at Golfech in 1995. Hourly rhythms may be influenced by certain parameters which affect the attractiveness, and therefore the efficiency, of the pass, such as turbining regime (Fig. 9).

Diadromous Salmonidae have a second wave of migration in the fall after the suspension in summer due to high temperatures (25° C as a daily mean appears to be the threshold for Salmonidae); without this unfavorable rise in water temperature in rivers in southwest France, it is unlikely that migration would cease as was observed in 1994 on the Dordogne. Activity is diurnal but with no high hourly maximum given the low numbers of migrants.

The migratory calendar of lamprey is similar to that of shad and is also in waves. Eels arrive much later, in July. Unlike shad, these two species have unimodal hourly nocturnal activity, with a maximum toward 2 a.m.

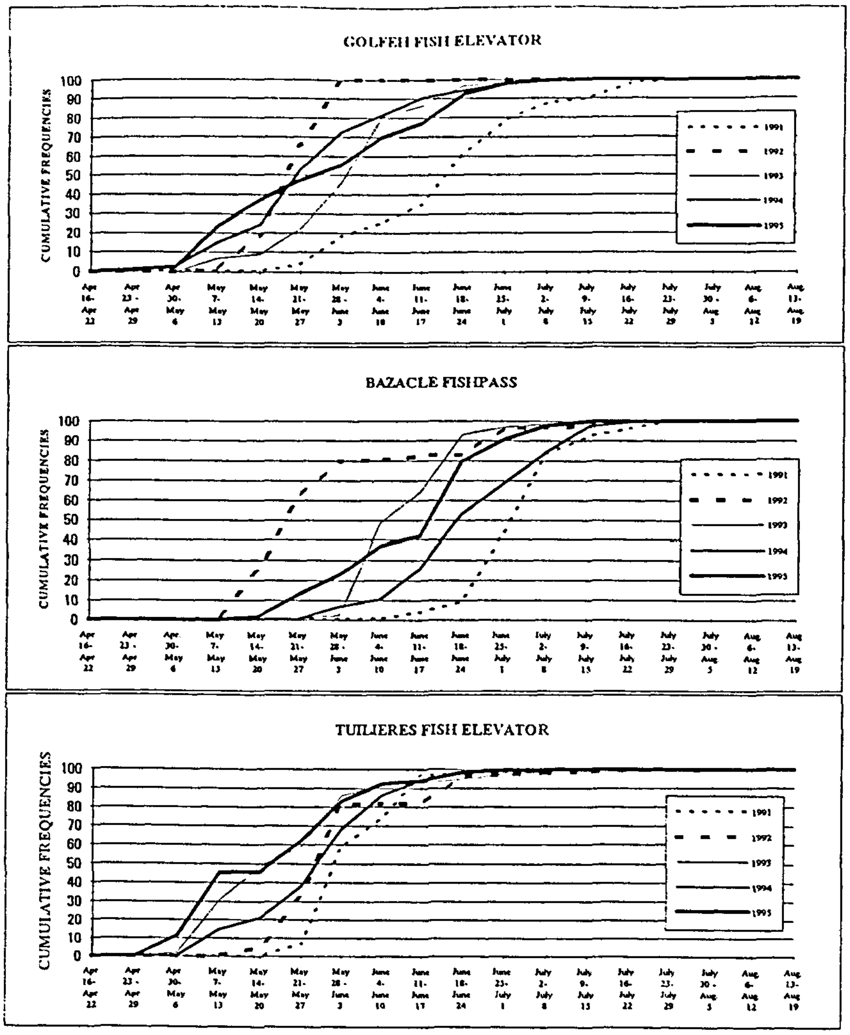


Figure 8 : Cumulated shad passages at Golfech and Tuilière fish elevators and Bazacle fish pass

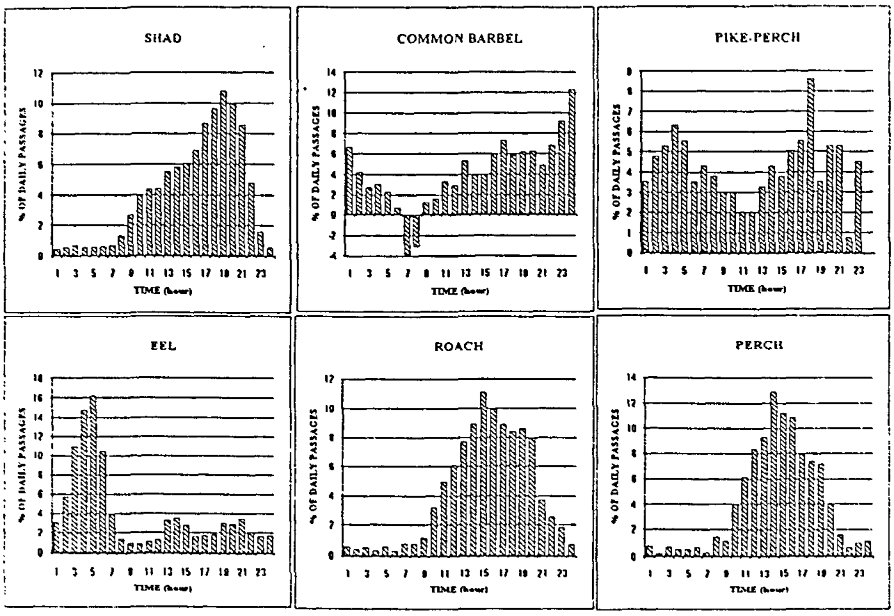


Figure 9 : Daily activity for several species at Tuilière fish elevator in 1995 (Dordogne river)

6.2.2. Migration of Cyprinidae

Cyprinidae are the family most abundant in both rivers, with close to a dozen species recorded at all our fishpasses. Barbel, bleak, bream and roach are traditionally the most abundant, whatever the site, and are found in thousands and tens of thousands, while carp, chub and tench only represent a few dozen individuals per year.

Seasonal activity of barbel really begins on a site like Tuilières only toward mid-March, whereas at Le Bazacle, further up the river, it begins only in mid-April, due to the later warming of the water (Fig.10). Migration ends with the heat of July and August, though some residual activity may persist until late fall, and, depending on environmental conditions, a resumption may be found, generally beginning in October. At Le Bazacle, the start of migration (5% of migrant stocks) has never been observed at temperatures under 11.5° C (daily mean). As for shad, migration is in waves, with high daily and hourly peaks. While hourly activity is spread over the 24 hours, it is more sustained in the second half of the day and the evening, and shows a significant decline in early morning.

Roach have the particularity among the Cyprinidae of having migratory activity not only before the spring reproduction period but also in fall, when there is almost as much displacement, and sometimes in summer, to a non-negligible degree. On all sites, this species is also the first to migrate in the year, in early March, and often the last in fall, in both cases with a relatively low water temperature: for the past three years at Le Bazacle, the first 5% of migration has never taken place at water temperatures under 11.8° C as a daily mean. Its spring migration extends from early March to mid-May in Tuilières and until early June at Le Bazacle, when it ceases even though environmental conditions are still favorable to other Cyprinidae. A second autumnal migration occurs from mid-September to the end of November, observed each year at Le Bazacle. In Tuilières in certain years, displacement is quasi-continuous, even in July and August when temperatures are very high (reaching daily means of 27.7° C in 1995). Depending on the time of year, the size of individuals observed varies, with larger individuals found in the spring migration, probably corresponding to mature individuals (20 to 25 cm), while later (in summer or fall), the size histograms are more spread out and large individuals are no longer in the majority. The hourly activity of roach takes the form of a unimodal diurnal curve, at its maximum in mid-afternoon. At Tuilières, differences are found in hourly activity depending on the time of the year, and appear to be linked to the thermal regime during the day. The difference between sites, such as those found between the Bazacle fishpass and the Tuilières elevator, may be due to the features of the pass as well as to the effects of turbining.

Most other Cyprinidae, who reproduce in spring and early summer, have migratory activity very similar to that of barbel.

For all Cyprinidae, as for most fish whose activity is observed by monitoring their displacement in the passes, it appears that a temperature of 9° to 10°C is a threshold for displacement.

6.2.3. Migration of carnivorous fish - Pike-perch and perch

The migratory behavior of various carnivorous species like pike-perch, perch, black bass and pike is somewhat similar, though they belong to different families.

Observation of the change in numbers of these various species from one year to the next at a site like Tuilières reveals constant progression. Perch and pike-perch are the most abundant and are found in the hundreds, whereas only a few dozen pike or black bass are found each year.

As most carnivoreous fishs reproduce in spring, it is natural in all cases to find a period of activity at that time, beginning in March and ending mid-May for perch, with the first warming of water (Fig. 10). The second period of migration is in fall, from early September to early December for pike-perch and perch, and to November for pike and black bass.

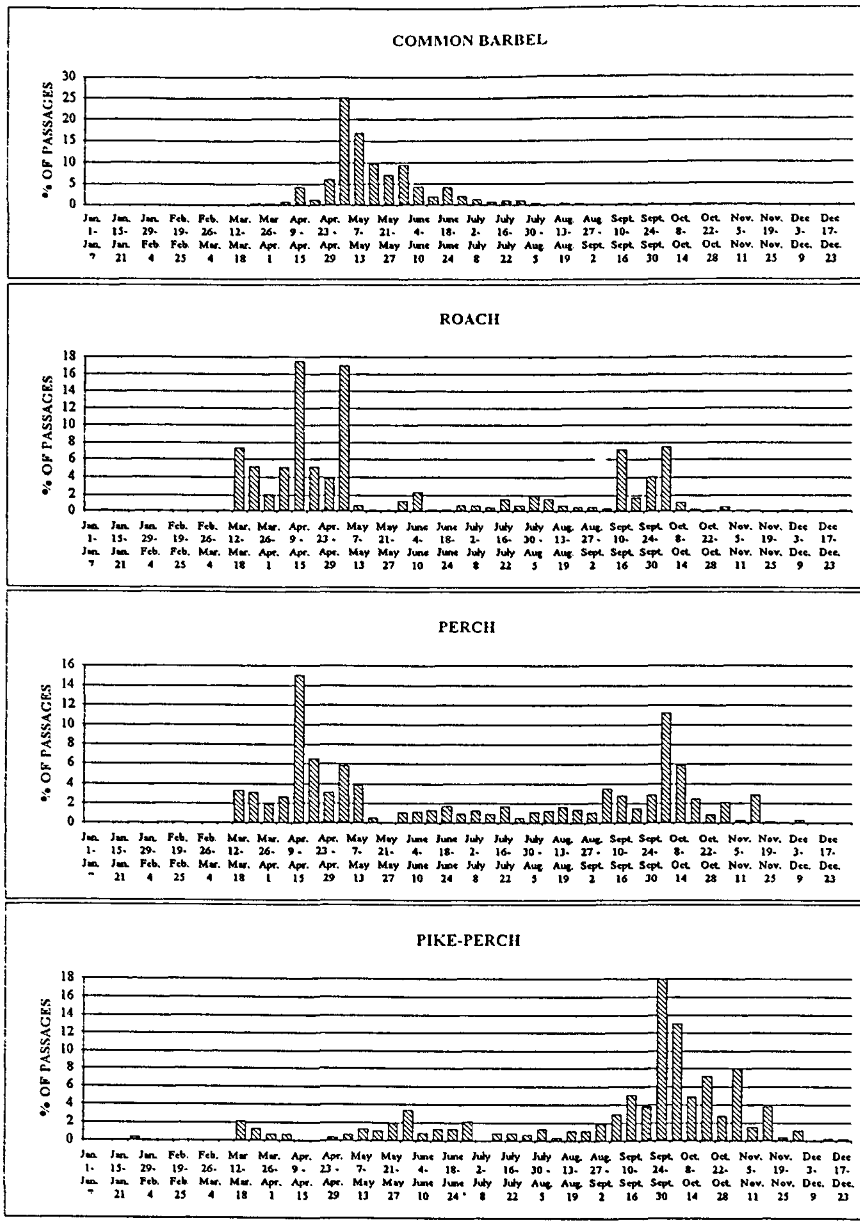


Figure 10 : Seasonal activity of severeal riverine species at Tuilières fish elevator (Dordogne river 1990-1995)

Perch, however, have non-negligible activity between these two periods, which persists through the high summer temperatures (in Tuilières, the temperature can reach 27° C during the day, as in 1995). Hourly activity of perch is diurnal and unimodal, centered toward the middle of the day (as for black bass and pike), whereas for pike-perch, is it more spread out, with a definite nocturnal tendency.

In conclusion, two features should be underscored in this presentation of a few characteristics of the migratory activity recorded at the different passes :

- aside from the biological need for reproduction, the principal factor influencing migration is water temperature, both in the seasonal calendar and in the daily, and even hourly migration rhythm,
- while the general springtime migration can naturally be explained by the need to reproduce in spring, this does not explain the significant displacement of certain species observed in other periods of the year.

CONCLUSION

The four fishpasses recently built on the Garonne and the Dordogne may now be considered to be operational on the scale of the two rivers, as they allow passage of some twenty species, including six diadromous migrant species, with numbers reaching several tens of thousands of individuals each year. In comparison with the relatively inefficient passes previously built at these dams, the new passes present several advantages: their type (vertical-slot pool-type fishpasses and elevators) which is suitable for most species, including shad; their sizing (discharge of 3 to 5 m3/s) in relation to the two rivers and their positioning in front of the plants, a preferential zone for the fish. Because of its operating principle, the fish elevator is only partially operational for small species like eel. Turbining lowers the attractiveness of the passes, but could be offset by the installation of several entrances. Regular monitoring of the installations proved necessary to ensure proper functioning. Particular attention must be paid to the auxiliary flow inlets and, on the elevators, to all mechanisms which must be closely watched during migration of shad. Thanks to the video counting stations in the passes, it was possible to gather valuable information on the migratory rhythms of all species, both for the purposes of optimizing the efficiency of the passes and for management of migratory populations.

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