Bull. Fr. Pêche Piscic. (2002) **364 suppl.** : 166-180

CHAPTER 12

MONITORING TECHNIQUES FOR FISHWAYS

F. TRAVADE (1) and M. LARINIER (2)

(1) Electricité de France, Research and Development, 6 Quai Watier, 78401 CHATOU Cedex - France.

(2) CSP-CEMAGREF, GHAAPPE, Institut de Mécanique des Fluides, Avenue du Professeur Camille Soula, 31400 TOULOUSE - France.

1. MONITORING FISHWAYS

Monitoring the performance of fishways and any functional controls associated with them are important operations for several reasons:

- To verify the efficiency of fishways after they have been commissioned and to adjust their operation if necessary.

- To gather technical and biological information which will be indispensable for the design and development of future fishways (operational feedback).

- To quantify migratory fish populations and describe the pattern of their migration, which is necessary both for the design of any fishways to be constructed upstream on the same watercourse and for rational stock management.

The techniques employed can be summarised under several headings:

- Monitoring the hydraulic and mechanical operation of the fishway.

- Collecting qualitative biological information indicating the effectiveness of fish passage.

- Counting fish using the fishway.

- Comparing the number of fish using the fishway to the migrating population as a whole, thus expressing the true efficiency of the fishway.

2. MONITORING HYDRAULIC AND MECHANICAL OPERATION

A number of simple measurements and observations should be made both at the time of commissioning and at regular intervals afterwards, to ensure that the fishway conforms to the criteria specified when it was designed.

2.1 Hydraulic parameters

Water levels at several specific points in and around the fishway (upstream, downstream, specific pools, etc.) must be measured. In pool type passes this should include the **water levels** and **head differences** for each pool and at the entrance to the pass. These measurements must be taken for several combinations of upstream and downstream water levels.

It must be verified that both the flow pattern and the level of turbulence at various points in the fishway remain compatible with the specific demands of the various species, *i.e.* plunging or streaming flows at each cross-wall between pools, presence of large recirculation areas in the pools, etc.

2.2 Mechanical parameters

In both baffle and pool-type fish passes the various regulatory facilities for controlling the discharge or the head differences between the pools, and at the downstream entrance (*i.e.* automatic gates) should be monitored. In “mechanical” fishways (lifts and locks), all the mechanisms essential to the operational cycle must be monitored and the duration of each phase of the cycle must be checked.

2.3 Obstruction and blockage of the pass

Particular attention must be paid to any obstructions caused by drifting debris. These may seriously hinder the passage of fish in certain critical areas (communication between pools, the water intake of the fishway, etc), or else they may reduce the attraction of the fishway (clogging of the screens for filtering the injection of auxiliary water). Either might occur without necessarily showing any obvious disturbance to the flow. In this regard submerged orifices must be checked very regularly and carefully.

3. GATHERING QUALITATIVE BIOLOGICAL INFORMATION

Apart from any quantitative analysis of the efficiency of a fishway a certain amount of indirect information can indicate whether its overall operation is satisfactory or not. Such information is all the more valuable if it is also possible to gather it before the installation of the fishway:

- Frequency of migrators leaping at the foot of the obstacle or the density of fish (if they are visible).

- Concentration of fishermen downstream of the dam (a sure sign that the fish cannot easily pass!).

- Observation of fish ascending the fishway.

- Indices of the abundance of fish (observation, capture) and counting of spawning activity upstream of the fishway (redds for salmonids and lampreys, “bulls” for shad -name of a group of spawning shad in south-west France).

This list is not exhaustive, and a certain number of other sources of information may be useful for qualitative analysis of the operation of a fishway.

4. COUNTING FISH IN FISHWAYS

4.1 Trapping

In principle, counting by trapping consists of catching the fish in a suitable facility installed either in the fishway or at its exit, and counting them manually before releasing them upstream.

The trap usually consists of a mesh cage or chamber fitted with a non-return system (inscale) placed inside the fishway. To recover the fish for monitoring procedures, or else to count them, the fish are concentrated into a small volume of water, either by partial emptying of the trapping facility or else by raising a grille from the base of the trap. In some cases fish will be transferred and counted manually, while in others, their numbers can be counted visually (Figure 1).

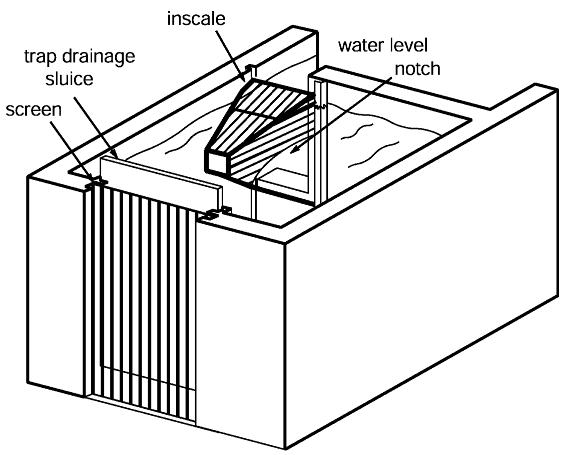

Figure 1: Trapping device used to count fish in small pool-type fishways. Fish are caught manually after the pool has been emptied.

The dimensions of the trap must allow for the maximum number of fish likely to be present in the installation at any one time. They will therefore depend on the daily migration peaks of the various species and on the frequency of operation of the facility. The volume of the trap is calculated by allowing a minimum volume of around 15 litres per kg of fish trapped (CLAY, 1961; BELL, 1986).

The most common dimensions of traps currently encountered in France are from 2.5 m to 4.5 m in length, from 1.5 m to 3.0 m in width, and from 1 m to more than 2.5 m in depth.

Counting operations must take place at regular intervals to avoid keeping the fish for too long. Usually this will be one or more times per day. Surveillance to prevent blockages and poaching is also necessary.

The costs of trap facilities vary greatly, depending on the size of the fishway, the sophistication of the handling system, and the characteristics of the species affected. They may vary from less than 1,500 € up to 25,000 €, corresponding to 1% to 10% of the cost of the fishway. The operating and maintenance costs of these installations are generally relatively high, chiefly because of the labour required for such operations. They also vary greatly from one location to another, depending on the abundance and nature of migrators, the degree of automation of the trap, and the need for cleaning and maintenance of the screens (which is often unpredictable). Depending on the site, between 0.5 and 4 staff will be required for trap management during the period(s) of operation.

The main advantage of this means of monitoring is that it is relatively easy to carry out, especially in small installations. Other advantages include the reliability of determining the species, the possibility of identifying the biological characteristics of the fish (size, weight, sex, etc.) and of removing individuals for marking or use as breeding stock.

The disadvantages are the risks of injury or stress to the fish (or even death for certain fragile species such as shad), the burden of maintenance including the high manpower requirement where the facility is on a large river, and also the impossibility of collecting continuous, real-time data. Another inconvenience, which is difficult to assess, is the negative influence of trapping on the efficiency of the fishway, since some species, such as shad, are reluctant to enter a trap.

4.2 Automatic resistivity counter

Resistivity counters are based on the principle that there is a difference in conductivity between the water and the body of the fish, *i.e.* the fish has a lower resistance than the water. The fish is forced to pass a series of submerged electrodes (three to five generally). The resistance between electrodes is permanently monitored and analysed by different means to detect the passage of fish, to determine the direction in which the fish is moving, and to classify it by size according to the peak signal size (Figure 2). Automatic adjustment of the sensitivity of the counter ensures that the sizes into which fish are classified remain consistent, despite variations in the conductivity of the water.

This type of counter is currently used in Great Britain where it was first the subject of intensive research in the 1970's by the Ministry of Agriculture, Fisheries and Food (MAFF), then later by others (BUSSEL, 1978; DUNKLEY and SHELTON, 1991; FEWINGS, 1994; NICHOLSON *et al.*, 1995). Various models have been marketed by Scottish Hydro-Electric plc (formerly the North of Scotland Hydro-Electric Board), by Sharkey Marine Electrics, and by Aquantic of Dingwall. Ets FRON and ELFES Electroniques in France have also developed a similar counter, in conjunction with CSP-CEMAGREF and INRA (BONNEFOIS, 1988; GOSSET, 1986) which was designed for easier maintenance and cheaper operation.

The geometry of the sensor may vary depending on the location. If the counter is installed in a fishway, then circular electrodes will usually be fitted in a tube located in a notch between two pools of the fishway. The diameter of the tube depends on the configuration of the fishway, its flow, and the minimum size of the fish to be counted. Diameters of tube currently in use vary from 0.30 m to 0.50 m.

The counter is usually linked to a data logger in order to capture temporal data on fish passage. Apart from its biological importance this information is needed to help eliminate false counts caused by non-fish artefacts.

Excessive turbulence and air entrainment, which may cause errors in counting, must be avoided. In order to achieve this, a level detector circuit interrupts operation of the counter if the depth of water over the electrodes is insufficient. In addition, a sufficiently high velocity must be used (greater than 1 m/s) to prevent the fish loitering between the electrodes.

Reliability of counting (which may exceed 80%) depends above all on the quality of the sensor location, and on the frequency of monitoring.

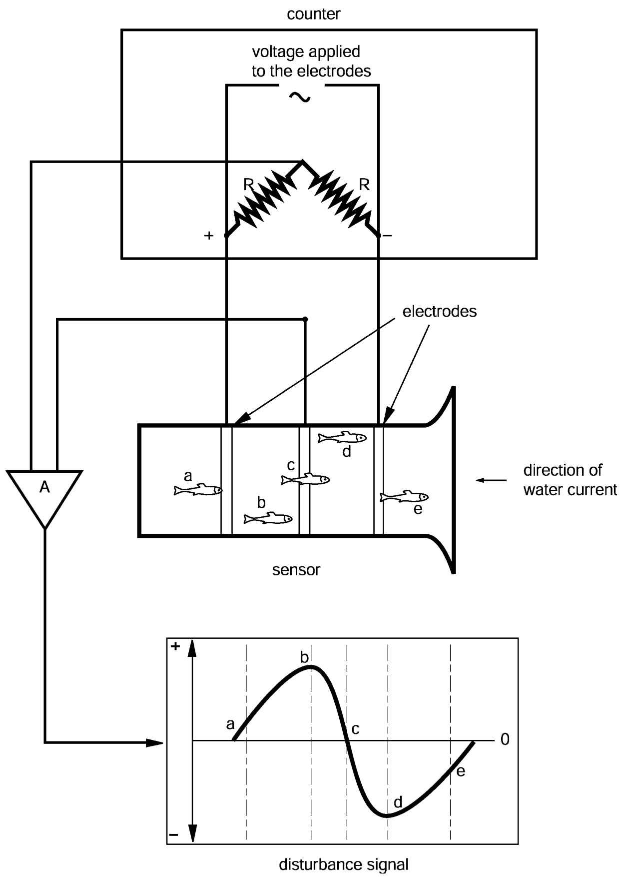

Figure 2: Principle of the functioning of an automatic resistivity counter.

An alternative to tube counting uses “Crump” weirs with the electrodes set into the downstream face of the weir. Advantages over tube counting includes a very low probability of blockage and visibility of passing fish or objects. Disadvantages include an increase in environmental adjustment problems due to variable depth and lower signal to noise ratios (FEWINGS, 1994).

Frequent monitoring (at least once per week) must be carried out by qualified staff. Whilst knowledge of electronics is not strictly necessary, the staff must have undergone minimum training to enable them to detect the principle causes of anomalies or malfunctions. These include damage to the sensor, loss of power, failures as a result of lightning strikes, etc.

The advantage of the counter lies in its low investment cost (around 6,000 € for the counter and between 1,000 and 2,000 € for the manufacture and installation of the sensor, depending on the site) and low maintenance cost (very low manpower requirement).

The major disadvantage inherent in this method is the absence of any means of discriminating between species other than by their size. In practice its use is restricted to river reaches where only a few species are present and can be distinguished using size criteria only (river reaches in trout zone where only trout, sea trout and salmon are present. It is still necessary to ensure that there is no risk of counting other migratory species on such reaches. In this respect the lamprey has proved to be a great nuisance because of its propensity to attach itself to the bed and remain stationary across the sensors.

4.3 Counting visually or by video recording

Visual observation provides a means of continuous counting without the need to handle or release fish, and therefore does not suffer the major physical disadvantages associated with trapping. It is accomplished by guiding the fish into an area where they are sufficiently visible to be identified and counted. Two techniques are used. These are external observation from above in which the fish is forced to pass through a shallow zone with a bright bottom against which it stands out in silhouette, and lateral observation in which the fish is forced to pass in front of a vertical window. The latter solution is to be preferred since it offers the advantage that the majority of species are more clearly identifiable from laterally-viewed morphological criteria.

In baffle fishways or pool-type passes external observation is facilitated by installing a horizontal observation plate upstream of a guide system for the fish (screen or notch in a wall). The observation plate is submerged to a depth not exceeding 0.30 m. In fish locks the plate is installed directly on to the upstream sluice. In fish lifts with small tanks (water depth not exceeding 40 cm) observation is carried out from directly above the tank, the bottom of which is painted in a light colour.

For lateral observation the passage of fish is narrowed (by deflecting fish with screens or by constricting the flow itself) in front of the window, thus forcing the fish to pass close by it. A minimum width of passage of 40 to 50 cm is usually adopted in order not to perturb the fish. It may be adjusted (0.30 m to 1 m) to adapt to variations in turbidity of the water. An observation plate in a light colour, and usually calibrated in order to give an indication of the size of the fish, is placed opposite the window (Figure 3).

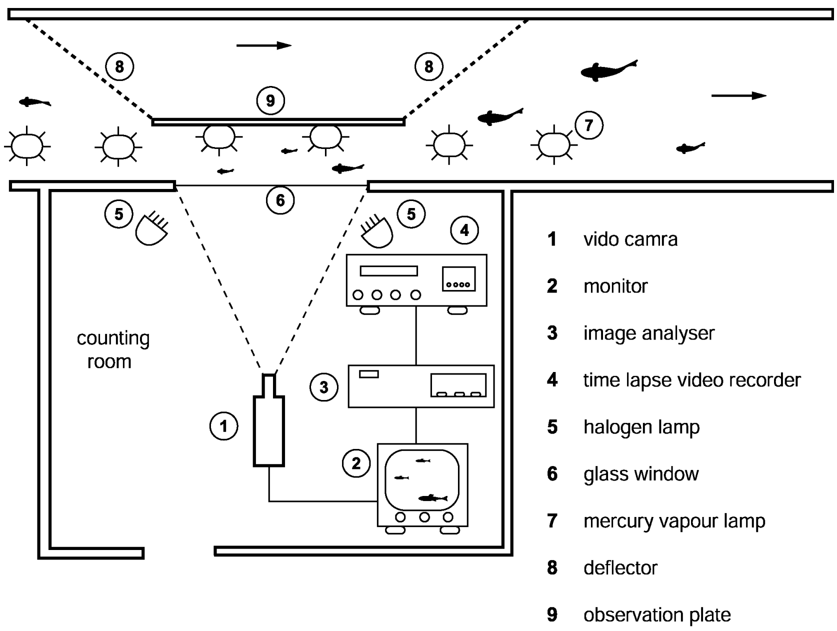

Figure 3: Schematic plan view of the automatic video fish passage recording system.

In order for conditions to be favourable for counting the fish they must pass in front of the observation equipment at a speed compatible with its capability for identifying the species in real time. They must not stop or swim back and forth in front of the counting facility. A flow velocity of around 1 to 1.5 m/s must therefore be maintained in the observation zone (this will vary with species and locations). The facility must be located as near to the upstream end of the pass as possible to overcome the problem of the high level of fall-back activity prevalent among certain species using fishways. Illumination of the observation zone is required in order to maintain optimum conditions of visibility at all times of day.

Furthermore, great care should be taken to avoid creating counter-currents in front of the window in which certain individuals and species will have a tendency to loiter.

Counting can be carried out in real time, requiring the presence of a full-time observer. This very time-consuming solution can be justified for very large fishways (Columbia river, USA) where fish passage is continuous. However, apart from the resource requirement (manpower intensive) it also has the additional disadvantage of not permitting any deferred analysis of those parameters which cannot be acquired in real time (size of fish, behaviour of different species and speed of passage).

Recent progress in the field of video technology, particularly in surveillance techniques, have allowed a certain degree of automation and reduced the need for visual counting carried out by observers *in situ*. Several solutions have now been adopted in France.

Automated monitoring of salmonids in small capacity fish lifts (water depth between 0.20 m and 0.40 m when being lifted) is facilitated by the discontinuous nature of passage. A video camera is fixed above the tank and a video recorder is switched on automatically for a few seconds during the ascent. An installation of this type has been operating on the salmon lift at Poutès on the river Allier (France) since 1986. It permits counting round the clock (12 ascents per day), and only requires one hour of analysis per month while having a counting accuracy better than 95%.

A similar method has occasionally been used at the fish lock at Soeix on the Gave d'Aspe et at Malause dam on the Garonne river. An observation plate was installed at the exit, on the upstream sluice. However, this method requires continuous filming during the filling and exit phases, and the analysis takes much longer than in the case of the lifts.

Two methods may be used with submerged windows where passage is continuous:

- Continuous low-speed video recordings and subsequent analysis of the speeded-up video tapes using a time-lapse video recorder. Recordings are made so that a standard three-hour video tape lasts 24 or 48 hours, *i.e.* the recording speed is reduced to $^{1}/_{8}$ or $^{1}/_{16}$ of normal. However, analysis can easily become a very long and painstaking operation. The analysis of a 24-hour tape may take from 3.5 to 5 hours if the number of fish is significant, owing to the need to rewind frequently to identify species;

- Automation of recording through detection of the fish when they arrive in the counting zone and then triggering of the video recorder to record the event only. The EDF Research and Development Division (TRAVADE, 1990) has used a system based on fish detection at the window itself by summary processing of the video image ("Cerbere" system, Figure 3). The system consists of a video camera that constantly films the window, connected to a time-lapse video recorder which can run at a very low speed (480 h for a standard 3-hour tape). However it actually records at normal speed when an external signal is given. This signal is generated by an image analyser normally used in security control devices (FOR-A SVS660, GEUTEBRÜCK, VIGIPACK), which detects the entry of fish in to the video frame. The system thus permits recording of only those sequences during which a fish is present in front of the window, whether ascending or descending. A certain number of sensitivity adjustments allow the configuration to be calibrated to suit the characteristics of the site and the fish.

Species identification and fish counting are carried out subsequently by viewing the tapes. These systems have been used successfully for more than ten years for counting round-the-clock at installations on major watercourses, such as Tuilières and Mauzac on the river Dordogne, and Golfech and le Bazacle on the river Garonne. It has allowed up to several thousand fish per day of more than 20 different species to be counted by a sole observer, providing valuable information on migratory patterns.

The theoretical duration of analysis varies between 10 minutes for 24 hours of observation for less than 10 fish per day, up to 7 hours for 24 hours of observation to count 5,000 fish per day. In practice, these figures depend on the environmental conditions (visibility, false start signals due to drifting debris) and especially on the species counted (ease in distinguishing species, speed of passage, passage individually or in shoals, fall-back activity and stopping in front of the window). Experience has shown that the average duration of analysis is around 4% to 10% of the real observation time (or 1 to 2.5 hours for 24 hours of observation) for low rates of passage (less than 400 fish per day). For high rates of passage (3,000 to 5,000 fish per day) it is from 15% to 20% of the real time (or 3.5 to 5 hours for 24 hours of observation).

Recently, a new numerical system has been developed in France (CATTOEN *et al.*, 1999) to record digitised images, and to interactively review recordings. Its aim is to reduce the time necessary to review analogue tapes such as those used in the Cerbere system. Images of fish passing in front of the window are digitised, compressed and numerically recorded on the hard disc of a PC (Figure 4). A software program permits both the reviewing of the records and the automatic generation of computer files of the results (Figure 5). The first trials, on 6 months of survey data, concluded that this new equipment could reduce the time necessary to count fish by a factor of 8 compared to the Cerbere system (about 11 h of work compared to 90 h for the analysis of data from the 6-month survey). Four monitoring stations are now equipped with this system in France.

The reliability of detection of fish in front of the window depends on various environmental factors (lighting, water turbidity for which a minimum of 0.70 m to the secchi disk is required), and on the species of fish in question (their size, colour, speed and swimming depth). On average, in good visibility, the reliability of detection is excellent (90% to 100%) for salmonids, shad and cyprinids greater than 25 cm in length; good (70% to 90%) for lamprey, barbel and cyprinids between 10 and 25 cm long; and fair (50% to 70%) for eels and fish shorter than 10 cm.

The lighting characteristics of the observation area are particularly important to the operation of the system, insofar as they affect both the ability of the system to detect the fish, and the behaviour of the fish themselves. It is possible to light either from above the surface of the water, or else to backlight by positioning the light source on the side opposite to the viewing window. With the latter type of lighting, the fish appears as a silhouette, and the species can be recognised from the shape.

Surface illumination above the window needs to be sufficiently powerful (approximately 2,000 W from halogen lamps, or preferably 500 W from mercury vapour lamps) to enable monitoring to be accomplished. It must extend in decreasing intensity several metres upstream and downstream of the observation area to reduce as far as possible any behavioural disturbances amongst the migrators (remaining in front of the window, turning back), especially at night. The back-lighting must be of a uniform intensity over the whole background to the counting area. An advantage of back-lighting over surface lighting is that better visibility is obtained when water turbidity increases. Back-lighting has now become the usual form of lighting since it is necessary for the optimal operation of the new digital equipment.

Figure 4: Screen during triggered recording

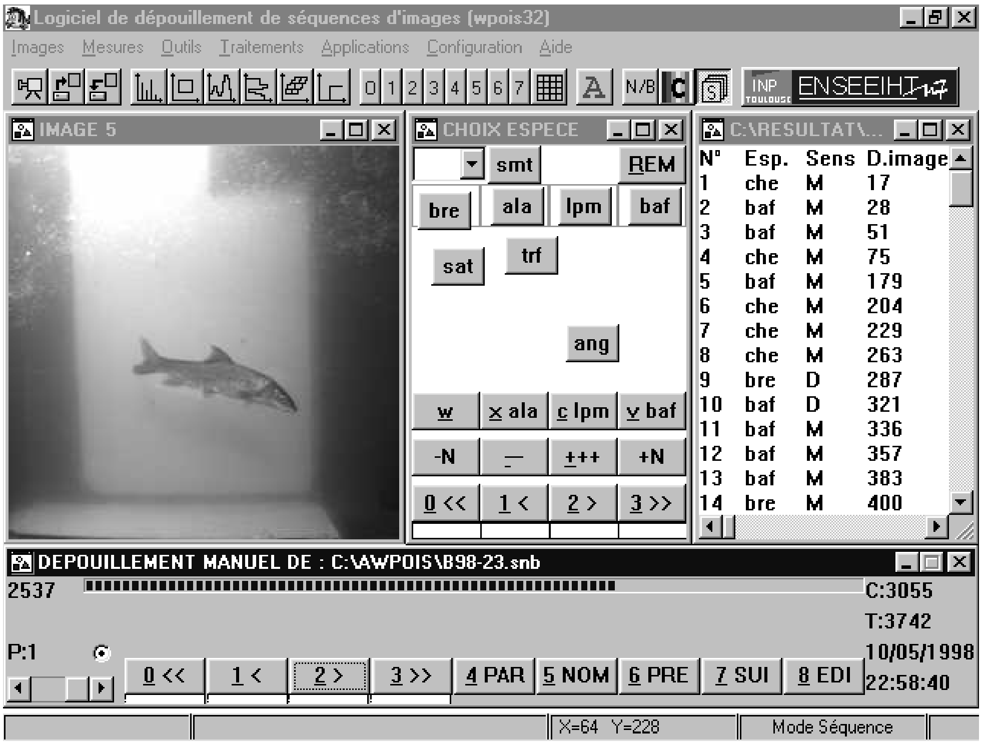

Figure 5: Screen during interactive reviewing

Regular checking (from three to seven times per week) to replace video tapes, check equipment settings, clean the observation window and fish passage zone is absolutely necessary.

The cost of installing an automated visual counting system includes both the cost of the counting station to house it (premises, guide system for the fish, lighting), and the video system itself. The cost of the counting station varies from 15,000 € to 50,000 €, depending on the characteristics of the site and the sophistication of the installation. The cost of a video system allowing continuous monitoring with simultaneous analysis (minimum of 2 video recorders, 1 video camera, two monitors) is as follows:

- From 2,500 to 5,000 € for a fish lift observation system (possible to use domestic video recorders).

- From 5,000 to 10,000 € for a “continuous” monitoring system, using “surveillance” video recorders without an automatic recording system.

- From 10,000 to 15,000 € for a system including an image analyser.

The advantages of visual counting are that handling of fish is not required, fish which are difficult to trap (shad) can be counted, less manpower is required than for trapping, and the migratory behaviour and patterns of all species can be determined very precisely.

The disadvantages are the impossibility of counting in very turbid water and the difficulty of identifying certain species. In the case of automated recording systems these disadvantages can be compounded by the limited efficiency of detection of some species, and by a sensitivity to drifting debris (especially water weed) which can cause false signals. In areas in which large numbers of species are present for a large part of the year the analysis of the video-tapes is also relatively painstaking and time-consuming.

Given the significant resources required for analysing visual counts of a large population of migrators, research has recently been carried out in France to design a fully automated counting system. (CASTIGNOLLES *et al.*, 1994a; CASTIGNOLLES *et al.*, 1994b, CATTOEN *et al.* 1999). The bases of this systems consists of real time automatic recognition of fish species on video images (by image analysis of fish shapes), together with automatic counting of each fish passing the viewing window whether in an upstream or a downstream direction. Good results were obtained in conditions when there was very low water turbidity, giving sufficient accuracy to recognise and count the fish whose shapes and sizes are very characteristic (large salmonids, shad, sea lamprey, eel, bream, barbel). However, at present, the use of this system in the field is not sufficiently reliable, mainly because it has proved to be impossible to recognise species when the water turbidity is high, and when too many fish are present at the same time in front of the window (overlapping shapes). Despite this, research has led to the design of the new numerical system described above (CATTOEN *et al.*, 1999) which allows for recording of digitised images and the interactive review of recordings.

5. ASSESSMENT OF THE ACTUAL EFFICIENCY OF A FISHWAY

The actual efficiency of a fishway is evaluated both in terms of the proportion of migrators present at the base of the obstacle that subsequently use the fishway, and in terms of the delay in migration. Two types of methods can be used.

5.1 Quantitative or statistical methods

The principle and most direct method consists of measuring or estimating the size of the population downstream of the obstruction and comparing it with the number of migrators using the fishway, determined by counting. The size of the population may be ascertained by counting fish taken in a trap or using a fishway further downstream, or by quantitative fisheries survey techniques.

An alternative and indirect method consists of marking a certain number of fish downstream of the installation and then counting the number using the fishway. The efficiency of the fishway is expressed by the formula:

$$E = 100 \ (Np/CNm)$$

where:

E is the efficiency of the fishway, expressed as a percentage;
Np is the number of marked fish entering the fishway
Nm is the number of fish marked downstream
C is a coefficient ($0<C\leq1$) expressing any influence of marking (mortality, etc.)

The migratory population present below the fishway can be estimated from the total count of fish passing the fishway:

$$Ne = C.N.Nm/Np$$

where:

Ne is the estimated population downstream of the fishway
N is the total number of unmarked fish passing through the fishway.

In practice, the greatest difficulty is in estimating the effect that marking has on the fish (coefficient C). This may be negligible for robust species (*e.g.* salmonids), but significant for some fragile species (*e.g.* shad) where marking may induce modified migratory behaviour or even a significant mortality rate.

5.2 Behavioural methods

These methods are intended to highlight the factors influencing the efficiency of fishways including siting of entrances, flow in the fish pass, and the effect of certain environmental factors. They involve the direct monitoring of the movement and behaviour of individuals when approaching installations. Telemetric techniques, based on the remote detection of a transmitter fitted to the fish using a suitable receiver, are used. Two systems of telemetric location of fish are available:

- Ultrasonic telemetry using transmitters in the 20-100 kHz band (STATSKO and PINCOCK, 1977). This has the advantage that it can be used to track fish in water of any conductivity (fresh water and seawater). However it has also the disadvantage of suffering interference from any ambient noise (turbulence, turbine operation, etc.), of requiring location by submerged hydrophones, and of being a high consumer of power which results in short transmitter life (a few weeks at most);

- Radiotelemetry using radio transmitters in the 20-180 MHz band (MCLEAVE *et al.*, 1978; SOLOMON, 1982, TRAVADE *et al.*, 1989). This has the advantage of being suitable for use with either aerial or submerged antennae that can detect the transmitter at relatively long distances (up to 2 km under optimum conditions). Other advantages are that it is not affected by ambient noise from watercourses or hydro-electric power stations, and it is energy-economical, (meaning that it is possible to use small transmitters with a life of several months). However, it is restricted to use in fresh water because of the high absorption rate of radio waves by water when the conductivity exceeds 300 to 400 µS/cm.

For this reason, radio tracking is essentially a technique used for monitoring river migrators (conductivity less than 400 µS/cm), whilst ultrasonic telemetry is generally used for estuarine and sea studies.

A small transmitter (weighing between 2 g and 25 g, depending on the size of the migrators in question) is either implanted in the fish internally (in the stomach or abdominal cavity) or else externally (usually on the dorsal muscle near the dorsal fin). In the case of large adult migrators which do not feed during upstream migration (salmon, shad) implantation in the stomach is the easiest method, and the one that involves the least disturbance to the fish. The fish is anaesthetised and the transmitter is pushed to the base of the stomach using an applicator tube. The antenna is either passed between the gill arches and back along the body, or, for more delicate species (shad), left in the maxillary angle.

The greatest care must be taken when handling the fish during capture and anaesthesia, and when implanting the transmitter, to prevent disturbance to its behaviour.

Tracking of tagged fish can be done in several ways depending on the size of the river, the nature of the study, or the required precision:

- Manual tracking:

The fish is located using portable overhead directional (loop or Adcock) or non-directional (whip) antennae, which can be carried on foot or on various vehicles (car, boat or aircraft). For high-precision location (to within several centimetres) it is possible to use submersible loop antennae fixed to the end of a pole. On very wide rivers the precise location of the fish will require bi- or triangulation, which entails finding the transmitter azimuths by using two or three receivers in fixed positions, the position of the fish being where the azimuths intersect.

- Automatic tracking:

The presence of fish within a zone can be detected automatically by a receiver, and then recorded by using paper recorders or data loggers (providing a means for direct processing of the results) connected to it. Depending on the size of the zone to be monitored it is possible to use overhead antennas (wide coverage) or submerged antennas (restricted coverage, *e.g.* a pool in a fishway). The presence of the fish within the zone is recorded as a function of time. The judicious combination of several recorders on a site will allow automatic tracking of fish movements by cross-referencing. These stations require receivers fitted either with scanners (automatic scanning of the frequency of each fish), or with receivers working in parallel on several channels.

The equipment used in recent studies in France (TRAVADE *et al.*, 1989, CHANSEAU *et al.,* 1999; CHANSEAU et LARINIER, 1999) originated in the USA (Advanced Telemetry Systems) and Canada (LOTEK).

The use of this technique is relatively expensive in terms of both equipment and manpower. An automatic listening station costs from 8,500 to 16,000 €, and a transmitter around 200-250 €. The transmitter must be considered to be expendable. One or two staff are required for a small programme using automatic radio-listening stations to study fish movements, and between 3 and 6 staff for a wider study involving manual location of the fish.

Although costly, this technique, which permits direct "observation" of fish behaviour both within and during their approach to fishways, has proved indispensable for obtaining information rapidly on fishway functionality and therefore in allowing certain specific aspects of their operation to be refined. It is also a very useful technique for determining and comparing the efficiency of several fishways located along a watercourse (CHANSEAU and LARINIER, 1999 ; CHANSEAU *et al.*, 1999; G. ARMSTRONG pers comm. about studies on the river Thames).

BIBLIOGRAPHY

BELL M.C., 1986. Fisheries handbook of engineering requirements and biological criteria. Fish. Eng. Res. Prog., U.S. Army Corps of Eng., North Pacific Div., Portland, Oregon, 290 p.

BONNEFOIS, P., 1988. *Le compteur à poissons type "FRON" au sein des techniques de comptage* (The "FRON" fish counter as a counting technique). CEMAGREF Rep., 110 p.

BUSSEL R.B., 1978. Fish counting stations (notes for guidance in their design and use). Dept. of the Envir., London, 97 p.

CASTIGNOLLES N., CATTOEN M., LARINIER M., 1994a. Fish species recognition using a bayesian classification process. J.Communications: Image processing II, 45, 21-24.

CASTIGNOLLES N., CATTOEN M., LARINIER M., 1994b. Automatic system for monitoring fish passage at dams. in: TESCHER A.G., ed., Applications of digital image processing XVII. SPIE, Int.Soc.Optical Eng., 2298, USA, 419-429.

CATTOEN M., LARINIER M., THOMAS N., 1999. *Système et logiciels pour la surveillance des passes à poissons.* (System and software for the monitoring of fishways). Bull. Fr. Pêche Piscic. 353/354: 263-277.

CHANSEAU M., CROZE O., LARINIER M., 1999. *Impact des aménagements sur la migration anadrome du saumon Atlantique (Salmo salar L.) sur le Gave de Pau (France)* (Influence of man made obstructions on the upstream migration of Atlantic salmon (*Salmo salar* L.) on the Gave de Pau river (France)). Bull. Fr. Pêche Piscic. 353/354: 211-237.

CHANSEAU M., LARINIER M., 1999. *Etude du comportement du saumon Atlantique au niveau de l'aménagement hydroélectrfique de Baigts (gave de Pau) lors de sa migration anadrome.* (The behaviour of returning adult Atlantic salmon (*Salmo salar*) in the vicinity of Baigts hydroelectric power plant on the Pau River as determined by radiotelemetry. Bull. Fr. Pêche Piscic. 353/354: 239-262.

CLAY C.H., 1961. Design of fishways and other fish facilities. Dept. of Fisheries, Ottawa, Canada, 301 p.

DUNKLEY D.A., SHELTON G.J., 1991. Recent developments in automatic fish counters for salmon rivers. Int. Council for the Exploration of the Sea, CM 1991/M, 27, 5 p.

FEWINGS G.A., 1994. Automatic salmon counting technologies. A contemporary review. Atlantic Salmon Trust Publication, Pitlochry Scotland, 66 p.

GOSSET, C., 1986. *Présentation et essais d'un compteur à résistivité pour poissons* (Presentation and trials of a resistivity fish counter). Bull. Fr. Pisc., 303: 141-151.

MCLEAVE J.D., POWER J.H., ROMMEL S.A., 1978. Use of radio telemetry for studying upriver migration of adult Atlantic salmon (*Salmo salar*). J. Fish. Biol., 12: 549-558.

SOLOMON D.J., 1982. Tracking fish with radio tags. Symp. Zool. Soc. Lond., 49: 95-105.

STATSKO A.B., PINCOCK D.G., 1977. Review of underwater biotelemetry with emphasis on ultrasonic techniques. J. Fish. Res. Bd. Can., 34: 1261-1285.

TRAVADE F., BOMASSI P., BACH J.M., BRUGEL C., STEINBACK P., LUQUET J.F., PUSTELNICK G., 1989. Use of radiotracking in France for recent studies concerning the EDF fishway program. Hydroécol. Appl., 1/2: 33-51

TRAVADE F., 1990. Monitoring techniques for fish passes recently used in France. Proc. Int. Symp. on fishways, Gifu, Japan, 119-126.

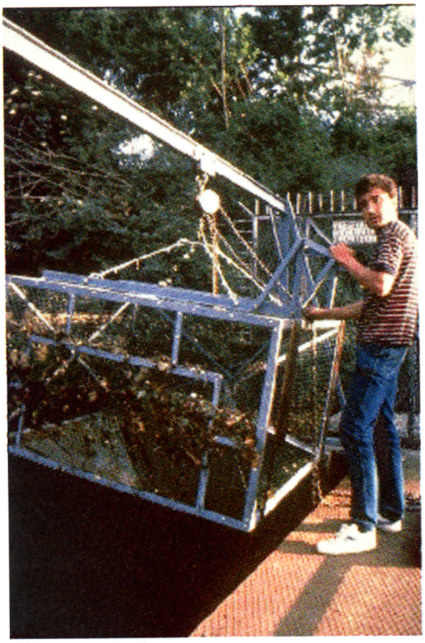

Photo 1: Mesh cage to trap fish installed upstream of a fishway.

Photo 2: Counting by lifting the bottom of a trap.

Photo 3: Trap installed in the entrance (upstream) section of a pool fishway.

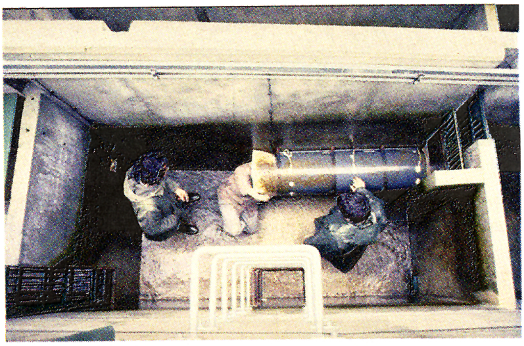

Photo 4: Tube sensor for automatic resistivity counter located in a notch of a salmonid pool fishway.

Photo 5: Four-tube sensor for automatic resistivity counter located in the upstream section of an eel climbing ramp.

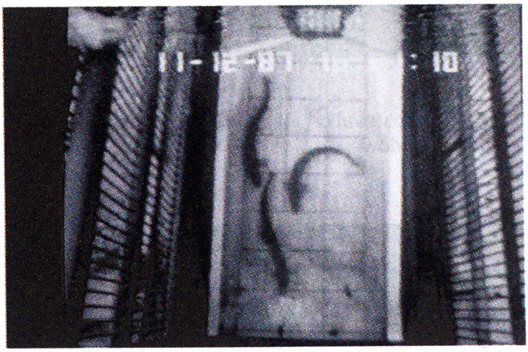

Photo 6: Video monitoring of fish during the raising phase in the tank of a fish lift.

Photo 7: The counting station at the Golfech fish lift on the Garonne river, view from upstream.

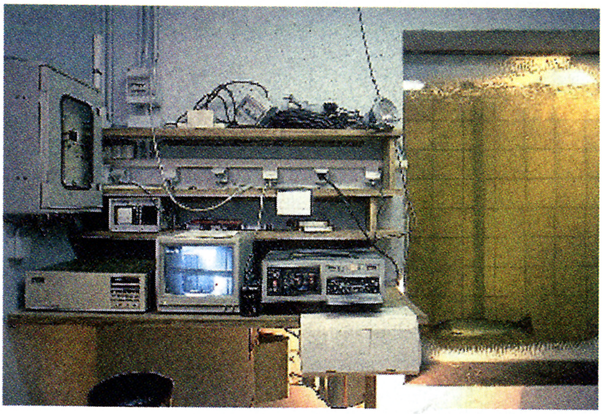

Photo 8: The automatic video counting system at the Golfech fishlift on the Garonne river.

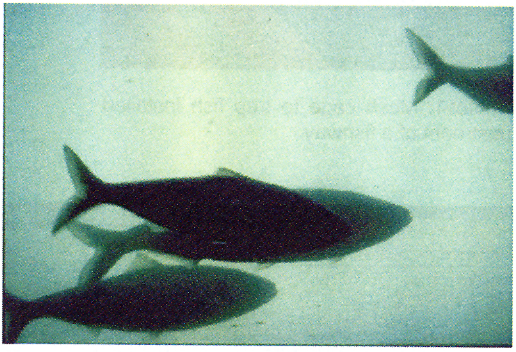

Photo 10: Observation of shad through a counting window with backlighting conditions.

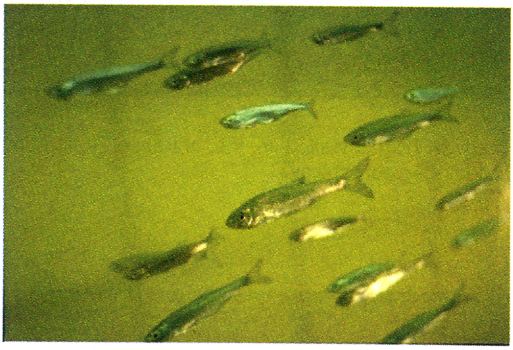

Photo 9: Observation of small cyprinids through a counting window.

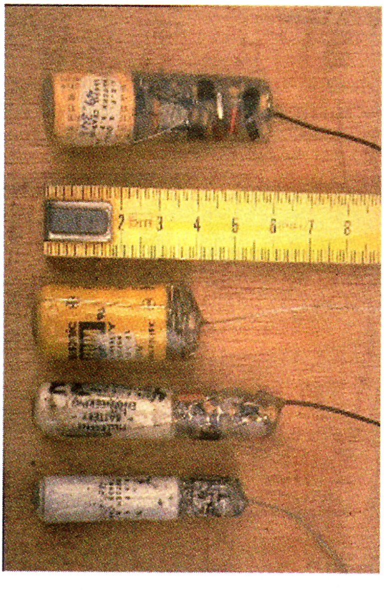

Photo 11: Miniature transmitters for adult fish radio tracking.

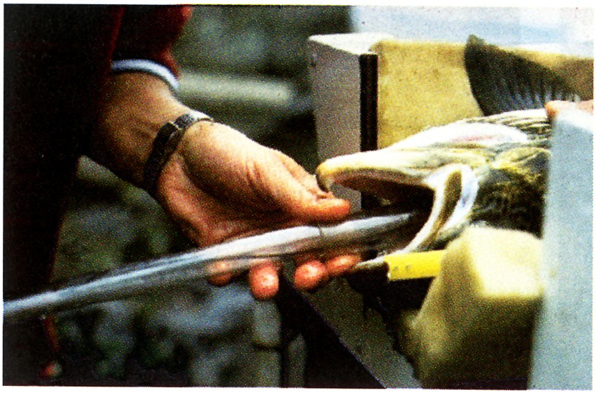

Photo 12: Marking a salmon with a radio transmitter.