Study of the crossing capacity of the brook lamprey (*Lampetra planeri*, Bloch, 1784) with a view to defining the criteria for dimensioning crossing devices.
Life nature "headwater streams and faunistic heritage associated"

Study of the crossing capacity of the brook lamprey (*Lampetra planeri*, Bloch, 1784) with a view to defining the criteria for dimensioning crossing devices.

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Summary

As part of the implementation of the LIFE programme "Headwater streams and faunistic heritage associated", a specific study of the dimensioning of crossing structures suitable for the brook lamprey was conducted in a controlled channel.

A device with a variable gradient ramp (5%, 7.3%, 8% and 12%) supplied with flows of 5 to 40 l/s and equipped with different substrates or partitions delimiting a succession of pools was used in Spring 2007 and 2008 during the migration of adult brook lampreys.

In total, 52 configurations were tested representing 78 tests with 650 lampreys placed in a crossing situation.

The adult lampreys showed a marked desire to cross the devices. It was not possible to determine their swimming capacity. Maximum speeds are of the order of 70 to 80 cm/s whereas critical speeds are close to 40 cm/s. Individuals in a crossing situation are capable of using their sucker mouth to fix onto any surface in order to rest between two periods of swimming.

Crossing rates for ramps equipped with partitions with vertical slots and slowing devices were very low (<3%), whatever the flow passing through. Similarly, whatever the substrate and the flow, gradients of more than 8% constitute limit values for the ascent of lampreys. Homogeneous substrates of the brush type or studs supplied with unit flows of less than 35 l/s/m of width constitute the best configurations for the crossing of adult lampreys (average of 59% of passages for the brushes, compared to 42% for "Evergreens", 40% for studs and 9% for ramps with an uneven bottom and regularly distributed stones). As regards the flows, the crossings decrease very markedly when the values are over 35 l/s per metre of ramp width.

For the 3 most effective substrates (brushes, Evergreens, studs), the crossings go from 91% to 55% then 20% for unit flows of 25, 35 and 50 l/s/m of width.

If we take into account the reliability and self-maintenance capacity of the devices, the "Evergreen" stud type substrate constitutes the best compromise. This support was also tested for the other species of fish in the headwater streams, namely, the trout, the chub, the stone loach and the minnow. For each of these species, the configuration consisting of a ramp with a gradient of 8% supplied by a unit flow of 35 l/s/m of width provides levels of effectiveness varying from 62 to 75% depending on the species.

The obstacles installed in the headwater streams can therefore be adapted to provide ecological continuity of the fish species beyond the brown trout using ramp-type devices with a maximum gradient of 8% equipped with dense bumps regularly distributed and supplied by quite low flows (<35 l/s/m of width). These devices, due to the dimensioning constraints mentioned above remain, however, reserved for obstacles of relatively low height (<1-1.5 m).

As part of the LIFE programme, a sill was equipped on the Valezin stream in the low Jura mountains according to the dimensioning recommendations defined thanks to the experiments carried out in a controlled channel.

Key words: ecological continuity, fish passes, crossing, brook lamprey, Lampreta planeri, chub, Cottus gobio, stone loach, Barbatula barbatula, minnow Phoxinus phoxinus, swimming speeds.
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1. CONTEXTS, OBJECTIVES AND CONDUCT OF THE STUDY.

The fragmentation of habitats is extremely detrimental for many species of fish whether they are migratory or holobiotic species. The re-establishment of ecological continuity constitutes a major issue in the ecological restoration of bodies of water, but also for the conservation of patrimonial species.

To achieve these objectives, it is necessary to have some knowledge of the movement behaviour of the species concerned, their capacity for crossing obstacles as well as on the technical solutions that can be used to re-establish free movement.

In this area, little information is available for headwater stream species such as the brook lamprey and the chub. Nevertheless, these environments are highly fragmented, as has been shown by studies conducted on the sub-basins of the Morvan massif (Couasné, 2003, Jaladon, 2004, Bontemps, 2005). The obstacles present on average every 0.8 to 1.2 km of stream are very often the result of road, agricultural or forest passages. They consist mainly of pipes, bridge foundations and concrete box drains. These obstacles, the majority of which are judged difficult to cross for brown trout, constitute blocking points for the other species with weaker swimming capabilities such as the brook lamprey.

Under the LIFE programme "Headwater streams and faunistic heritage associated", two sites were chosen where actions to reconnect the tributaries with the main water course were envisaged in order to guarantee the free movement of the brook lamprey. To be able to propose suitable technical solutions, it became clear that it would be necessary to conduct some initial work on the species' swimming and crossing capabilities in an experimental channel.

Over the course of the springs of 2007 and 2008, studies were carried out in an experimental channel at the fish farm at Vermenoux (58). The aim of this work was to:

- get an idea of the swimming capabilities of adult brook lampreys,
- test the crossing possibilities of this species with regard to the different technical solutions characterised by different substrates and different flow conditions,
- define dimensioning criteria for the structures specific to this species.

At the same time, tests were also done on the species present in the same environments as the brook lamprey, namely the chub, minnow, loach and brown trout. These complementary tests were mainly intended to check that the technical solutions adapted to lampreys were not detrimental to the other species of fish in the streams.

The 1st part of this report contains a reminder of current knowledge on the brook lamprey. The 2nd part is devoted to a description of the experimental devices. The results are presented and discussed in the 3rd part.
2. REMINDER OF CURRENT KNOWLEDGE ON THE BIOLOGY OF THE SPECIES STUDIED

2.1. Taxonomy, distribution and general biology.

The stone (*Lampreta planeri* Bloch, 1784) is one of the 3 species representing the Petromyzontiformes order and the Petromyzontidae family in France with the river lamprey (*Lampreta fluviatilis* L.) and the sea lamprey (*Petromyzon marinus* L.). It should be noted that the brook lamprey and the river lamprey are considered as 2 "paired" species (Hardisty and Potter, 1971), *Lampreta planeri* constituting a non-parasitic form of *Lampreta fluviatilis*.

The distribution of the brook lamprey across France remains widespread (Keith and Allardi, 2001) with colonisation of all the major hydrographic basins. This species is typologically situated in the lower trout section and grayling section, although it also colonises the habitats of the upper trout section. Its optimum abundance is situated at typological level B5 (CSP DR5, 1995). By way of example, in Burgundy, the brook lamprey is present in many water courses up to the headwater stream, although with fragmented distribution.

In an analysis of 446 fishing sites, lampreys were found to be present in 28% of cases (53% for the chub) with a distinct difference between rivers over 5 m wide where the lamprey is found in 1 station in 2, whereas it is only present in 10% of headwater streams (<2.5 m) (15% in the Morvan) (Baran *et al.*, 2009). In hydroecoregion terms, few differences were found between the eastern chalky hills and the Morvan. However, it is poorly represented in the water courses of the Saône and Loire valleys (20% of sites more than 2.5 m wide). Its absence was also noted in the Morvan massif downstream of the large dams.

2.2. General biology and metamorphosis.

One of the specific characteristics of the Petromyzontiformes lies in the late metamorphosis (Grasse, 1957). Lampreys have a larval phase (called ammocete) which lasts most of their life (Grasse, *ibidem*). The duration of this larval phase varies, according to the different authors, from 4 to 6 years (Zanandrea, 1953; Keith and Allardi, *Ibid.*). The ammocetes live in fresh water in zones with loose substrates and low flows, where their diet is that of a microphagous filter feeder (Grasse, *Ibid.*; Keith and Allardi, *Ibid.*; Kelly and King, 2001). They undergo a metamorphosis to enter the short-lived adult phase in order to reproduce (Grasse, *ibidem*). This metamorphosis occurs for the brook lamprey when its body has reached a length varying from 12 to 15 centimetres (Maitland, 2003) and takes place between September and November preceding reproduction (Keith and Allardi, *Ibid.*). The animal then passes from a buried, filter feeding lifestyle to that of a carnivorous migratory swimmer (for the sea lamprey and river lamprey) or to one where it does not feed (brook lamprey). Consequently, the transformations will particularly affect the locomotor apparatus (fins), the sensory, buccal and pharyngeal organs (Grasse, *ibidem*).

Reproduction takes place in June mainly depending on temperature conditions. It begins when the water reaches at least 10°C (Bird and Potter, 1979; Bohl and Strohmeier, 1992). It takes place in groups. Lampreys choose very specific areas, particularly in terms of the substrate, preferring small gravel (0.2-2 cm) supplied by a regular current (0.2-0.3 m/s) (Maitland, 1980; Sokolov *et al.*, 1992). The breeding grounds are often situated in the flat facies at the junction with inverts. Lampreys build circular nests using either their mouth suckers or rapid movements of the caudal fin to move material. The female produces from 1000 to 1500 eggs. Adults spawn only once then die soon after.

2.3. Movements.

The brook lamprey's movements are poorly documented. According to the authors, there is a great disparity in the distances covered. For some, the brook lamprey can migrate over
"considerable distances" (Igoe et al. 2004), for others, the species is capable of covering distances of two kilometres (Malmqvist, 1980; Jacquet, 1996), or less, just a few hundred metres (Kelly and King, Ibid.). This upstream migration is considered as a compensatory mechanism for the phenomenon of the downstream migration of the ammocetes. The migration period also differs according to the authors. Thus, according to Maitland (2003), migration takes place in the autumn. Once the area of the breeding ground is reached, the adults hide under stones or in the vegetation and wait for March or April and the temperatures conducive to reproduction. For others (Malmqvist, Ibidem), it takes place in spring. During their migration, the breeding animals undergo anatomical changes, in particular a reduction in the length of their body.

2.4. Crossing structures and dimensioning criteria.

A fish's capacity to cross an obstacle depends on its mode of locomotion (swimming, crawling) which is itself linked to intrinsic parameters (shape of the body and fins, physiology) and environmental factors (temperature). For the lamprey, information concerning its swimming and crossing capabilities is very patchy. Only some studies on the migrating larvae of the Pacific lamprey are available (Moursund et al., 2003; Dauble et al., 2006). For sizes close to those of the breeding brook lamprey (135 mm), the authors have determined a maximum swimming speed of 71 cm/s or a ratio of 5.2 fish lengths per second and critical speeds of the order of 30-40 cm/s.

The anatomical changes occurring in the lamprey on metamorphosis allow it to acquire swimming capability. The larvae are much less suited to swimming (relatively undeveloped fins) and to fixation (absence of the mouth sucker) (Grasse, Ibid.) and therefore to resisting the currents that exist in the breeding grounds. They will be subject to the phenomenon of downstream movement (Hardisty, 1944). Conversely, the adults are equipped with buccal disks enabling them to attach themselves in current zones, and with more developed fins (Grasse, Ibid.). It should, however, be noted that the size of the fins remains small, which will impact the species' movement capacity. Breeding animals may, however, benefit from their ability to fix onto a support thanks to their mouth sucker, as this gives them the possibility of resting in strong flow conditions.

3. EXPERIMENTS IN AN ARTIFICIAL CHANNEL

The study of the crossing capacities of the brook lamprey was carried out in a controlled environment. Indeed, the lack of data, or contradictory data on the behaviour of this species make it difficult to monitor them in the wild. As a result, it was decided to set up experiments in a fluvarium in order to facilitate observation. This fluvarium was set up at the Vermenoux fish farm and supplied with water from the River Yonne. At the fish farm level, this river contains a population of brook lampreys, chub, minnow, loach and brown trout. The presence of larvae in the water courses supplying the device may be an important factor in the success of the experiments. Kottelat and Freyhof (2007) indicate that larvae seem to release pheromones attractive to the migrating individuals. The choice of this site would therefore provide for the tests and holding tanks conditions identical in terms of water quality to those of the species' own environment.

3.1. Experimental installation

3.1.1. Presentation of the experimental device


The device consisted of an upstream tank and a downstream tank connected to each other by a single channel (Fig 1). This 4 m long channel consisted of CTBX plywood planks 19 mm thick, opening on one side to enable a Plexiglas "window" 80 cm x 34 cm to be installed. The
inside width of the channel was 30 cm and its depth 25 cm. Rigidity was provided by 10 cm x 10 cm x 380 cm wooden cleats placed under the floor of the channel and by metal corner reinforcements placed at regular intervals above the channel. At each end, two 25 mm flat metal slides were fixed on either side to fix it to the entry and exit tanks. Entry and exit to the channel was via two tanks (170 x 150 x 65 cm for the upstream tank, 200 x 150 x 40 cm for the downstream tank).

The fluvarium was supplied with water by a sluice gate at the entry to the tank delivering flows varying from 4.5 to 6 l/s. The water was taken from the River Yonne. The gradient of the ramp was fixed 7.3%.

3.1.1.2.Device used in 2008.

In 2008, the experimental device consisted of an upstream tank containing hides made of stones and PVC tubes, a downstream tank and two 4 metre long, 40 cm wide ramps each with a different gradient connecting the two tanks (Fig 2).
The ramp gradients were initially fixed at 8% and 12% according to the results obtained in 2007 (Baran and Pesme, 2007). These values correspond to the extreme gradient conditions that the species seems able to tolerate. However, after the 1st tests, the 12% ramp rapidly showed itself to be rather uninformative. It was replaced by a 5% ramp on 30 April 2008. The upstream tank was supplied by a rack and pinion lift gate enabling the flow entering the device to be varied. The flow was injected directly and dissipated by passing through stones before falling into the upstream tank.

3.2. Biological material

3.2.1. Collection of individuals:

In order to constitute a sufficient stock of brook lampreys, electric fishing was conducted using a "Dream Electronic kingfisher" on the Yonne as well as on one of the tributaries on its left bank. Two fishing campaigns were conducted in 2007: on 13 and 19 April and three campaigns in 2008: on 3 April (17 adult individuals collected, buried in the sediment with larvae), on 14 May (0 individuals collected) and on 20 May (2 adults collected, under the fish farm sill). The adult individuals as well as the larvae were kept for the tests in 2007. In 2008, only the adult individuals were selected. Indeed, only this stage is liable to migrate (Grasse 1957, Keith and Allardi, 2001, Baran and Pesme, 2007). In view of the protective measures in force concerning this species and its environment, capture authorisations were requested from the relevant authority, the Burgundy DIREN. As well as lampreys, chubs, loaches and minnows were also captured and used in the tests. In 2008, farmed trout from the fish farm were also included in the tests.
3.2.2. **Holding the individuals**

The individuals captured were held in the fish farm. They were placed in a tray with a lid (to protect them from the light and limit their stress), situated in a tank in the open circuit of the fish farm and constantly supplied with water. The water in this circuit is taken directly from the Yonne and has the same characteristics as the capture environment.

3.3. **Configurations tested.**

3.3.1. **Preliminary study in 2007.**

3.3.1.1. *Experiment plan*

In 2007, the work done aimed to check the feasibility of the experiments and to launch the 1st tests on the crossing devices. The work was therefore conducted for a fixed gradient of 7.3% and a relatively stable flow of between 4.5 and 6 l/s (or 13.5 to 18 l/s/m of channel width). In total, 15 tests were carried out with four types of ramp device:

- stone sills (4 tests),
- partitions with vertical slots (9 tests),
- chevrons (1 test),
- small stones scattered on an uneven bottom (1 test).

3.3.1.2. **Stone sills**

Six sills were installed in the ramp. They consisted of stones with heights varying from 10.5 to 14 cm. A weir was created in each sill with a width varying from 16 to 18 cm for a weir height of 4 to 6 cm.

![Figure 3: View of the sills installed in the ramp with a flow of 5 l/s.](image)

3.3.1.3. **Vertical slots.**

25 cm high partitions were installed in the ramp with vertical slots 5 cm wide (Fig 4). Depending on the test, the number of partitions varied from 5 to 7.
3.3.1.4. Chevrons or slowing devices

Chevrons consisting of plastic boards were fixed on the bottom of the ramp as slowing devices. Nine chevrons 4 cm wide fitted on the bottom of the ramp. They each form an angle of 120° facing upstream (Fig 5).

3.3.1.5. Uneven bottom and regularly placed stones.

A final test was performed with an irregular surface over all the bottom of the ramp. This irregular surface consisted of gravel and stones with a diameter varying between 1 and 5 cm. Eleven large riverstones (diameter 8 – 15 cm, height 12 – 18 cm) were placed in the centre and on the sides of the ramp (Fig 6).
3.3.2. 2008 study.

3.3.2.1. Experiment plan

In view of the result of the tests carried out in 2007, an experiment plan was drawn up combining:

- 2 different ramp gradients (8 and 12% at the beginning, then 8 and 5%),
- 5 types of substrates (brushes, studs, Evergreen slabs, stones/gravel and regularly placed stones, stone sills),
- 4 different flow ranges (<10 l/s, 10-15 l/s, 15-20 l/s and >20 l/s), or for a 40 cm wide ramp values of 17.5-25 l/s/m, 25-37.5 l/s/m, 37.5-50 l/s/m and >50 l/s/m,
- 2 periods: day and night.

The potential number of configurations combining the different conditions of each of the parameters (gradient, substrate, flow, period) would have been 120. If we had repeated each configuration at least twice, that would have brought the number of tests to 240, which would have been totally unrealistic given the possible duration of the experiments (60 days maximum) due to the weakening of the fish. Indeed, the physiological decline of the individuals used was relatively marked in the last 10 days of the experiments. In the migratory phase, brook lampreys stop feeding (Grasse, 1957; Keith and Allardi, 2001). Consequently, their energy available for the movements drops rapidly. The tests conducted at the end of the migration period would therefore contain a certain bias, given the physiological condition of the lampreys.

It was therefore necessary to reduce the number of configurations tested. To do this, adjustments were made as the results were obtained. A substrate that was found to be ineffective at the lowest flows was not tested at higher flow values. Similarly, as will be presented in the results, the night tests revealed considerably less active movement behaviour than in the daytime. Thus, the nighttime tests were soon abandoned.

Thus, taking account of these different elements, 43 configurations were tested representing 63 tests with 584 lampreys placed in a crossing situation (table 1).
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<td></td>
<td>4 (N=41)</td>
<td>1 (N=9)</td>
<td>NE</td>
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</table>

Table 1: experiment plan presenting the number of tests carried out in each of the configurations tested, combining the gradient, substrate, flow and period conditions. (N= number of individuals introduced, NE: no test done).
3.3.2.2. Uneven bottom surface and alternating stones

Riverstones of restricted diameter (2.5 to 7 cm) were placed over all the bottom. The aim of this device was to reduce the speeds by a rough bottom surface and a succession of stones (Larinier et al., 2006). Strips of plastic were placed in advance in alternating positions on the bottom of the ramp in order to avoid the riverstones being carried downstream during the experiments. Ten larger stones (height 20 to 25 cm and diameter 12 to 15 cm) were installed corresponding to a concentration of 0.18 (Fig 6).

3.3.2.3. Stone sills or rustic sills

This device consisted of a variable number of sills depending on the experiment (5, 6 or 7). Each sill was made up of stones 20 to 25 cm high and gaps consisting of stones 5 cm high to make a weir (Fig 3). Three widths of weir were to be tested initially (10, 15 and 20 cm). However, the first results obtained were not at all conclusive, and this device was quickly abandoned in 2008.

3.3.2.4. Eel brushes

This device was developed to facilitate the crossing of certain fish passes by the European eel (Anguilla anguilla L.). It consists of a board onto which are fixed a number of tufts of plastic fibres, with variable densities and lengths (Fig 7). Due to the homomorphy between the lamprey and the eel, it was decided to test this type of device, although the two species’ modes of crossing are different (crawling for the eel and jerky swimming interrupted by rest periods for the lamprey).

The brushes used in this study consisted of boards with tufts of plastic fibres 7 cm high spaced 3.5 cm apart in line. The lines were spaced 1.5 cm apart. Finally, there were 656 tufts on a board 1 metre long and 40 cm wide.

Figure 7: Ramp equipped with an "eel brush" type device (1), use of the brushes by eelers (2) and a brook lamprey (3).
3.3.2.5. *Eel studs*

This is also a device used to help eels cross certain passes. This device consists of plastic boards with small studs 2.5 cm high and 3.5 cm wide at the base (Fig 8). They are placed in line facing the flow. Eels cross this type of device by snaking between the studs.

![Figure 8: Ramp equipped with an "eel stud" type device.](image)

3.3.2.6. *"Evergreen" studs*

This device is in fact a type of paving used for grass car parks in order to avoid the formation of ruts. It consists of a moulded concrete slab forming asperities and hollows (Fig 9). This type of slab can be obtained from green space retailers. This type of device has been installed on certain dams to enable eels to cross.

![Figure 9: Ramp equipped with an "Evergreen studs" type device.](image)
3.4. Conduct of the tests

The tests were carried out in spring, which correspond to the species' migration phase. In 2007, they took place from 13 April to 25 May and from 9 April to 23 May in 2008.

3.4.1. Biological monitoring

3.4.1.1. Introduction of the fish to be tested

The individuals of the species to be tested are taken at random from the holding tray. No more than 9 to 12 lampreys are used in the same test, for two reasons: first of all, it is relatively complex to recapture all the individuals initially placed in the ramp at the end of the test, and it also allows a certain turnover of individuals during the tests, which limits their weakening. Certain tests carried out in spring 2007 were done with very small numbers of lampreys (4) due to the high mortality rate suffered by adult fish at the end of the migratory period. A cage was placed at the base of the ramp to be tested in the downstream tank in order to orient the lampreys (Fig 2). The animals were measured individually and placed inside, which allowed them to find the entrance to the ramp more easily and also obliged them to climb due to the lack of hiding places and the continuous presence of a current.

3.4.1.2. Duration of the tests

In 2007, the tests were carried out over variable durations ranging from 1 to 3 hours for the daytime tests. The nighttime tests were started in the evening and stopped the following morning. In 2008, in order to complete all the tests planned, each one was carried out over a period of 45 minutes to 1 hour.

3.4.1.3. Conditions of observation.

Three types of behaviour were observed:

- complete crossing of the ramp by an individual at the end of the test,
- partial crossing of the ramp at the end of the test (presence of fish in the ramp at the end of the test),
- failure to cross the ramp (the fish is still in the cage).

Individuals making attempts to cross, but ending the test in the ramp were considered as failing to cross.

In 2007, the movements during daytime tests were continuously monitored by the operator. On the other hand, for the nighttime tests, the monitoring was based on the inventory of the fish at the end of the experiment (in the upstream tank, in the downstream cage and in the ramp).

In 2008, a monitoring system was set up using cameras. Two cameras were installed at either end of the ramp enabling the movements of the lampreys in the ramp to be monitored. For each test, the inlet of water was cut off at the end of the experiment and the individuals were collected using a scoop net or by hand separating the individuals present in the cage, in the ramp and in the upstream tank. This operation is a very delicate one. It is indispensable to recover 1st of all the fish present in the ramp taking care to ensure that the reduction of the flow does not carry the fish immediately back to the cage. Generally, species that swim in open water such as the trout or minnow rapidly cross the ramp when the configuration is compatible with their swimming capabilities. They therefore do not remain in the ramp for
very long. On the other hand, lampreys, chubs and stone loaches make slower progress, in successive stages. They may therefore be presents near to or in the substrate at the end of the experiment and therefore be carried back downstream when the flow is interrupted. It was therefore necessary to proceed very meticulously.

After being recovered, all the individuals were measured $(\pm 1\text{ mm})$.

Given that the same individuals were re-used in several manipulations, it would have been possible to envisage some form of marking to identify each of them. However, the methods of marking that have been tried out on this species do not seem to be optimal. Injection has been tried using the Alcian Blue inoculator technique in the dorsal fin (Jacquet, 1996). But this method of marking seems to weaken the lampreys. Indeed, the fins are highly vascularised and small haemorrhages can occur. As a result, it was decided not to proceed with this type of manipulation.

The video monitoring tapes were examined in order to check the numbers of individuals in each part of the fluvarium (cage, ramp, upstream tank). Essentially they made it possible to monitor any movements of the fish back downstream from the upstream tank.

**3.4.2. Metrology of the environmental characteristics.**

**3.4.2.1. Measurement of the flows tested.**

During the 2007 experiments, the flow could not be controlled by the operator as there was no sluice gate. Consequently, the water level of the Yonne influenced the flows circulating in the ramp. The latter varied from 4.5 to 6 l/s or 15 to 20 l/s per metre of width. In 2008, the flow was controlled using a manual lift gate. The value was defined according to the height of the lift gate opening and the head.

**3.4.2.2. Hydraulic characteristics in the ramp**

The installation outdoors and on a fish farm was essentially intended to carry out biological tests. It was not possible to make accurate hydraulic measurements able to characterise the flows and in particular the speeds in the 3 dimensions.

Spot measurements were nevertheless taken at 12 points in the ramps in order to obtain water depth and current speed values. The depths were measured with a ruler. These measurements remain approximate given the instabilities of the water level and the fluctuations in the draught. The speeds were measured using a March MacBirney type current metre, model 201D at several depths depending on the flow and substrate configurations tested.

**3.4.2.3. Other parameters monitored.**

Two environmental parameters were measured and/or evaluated during the experiments.

- Water temperature: a temperature probe was installed in the fluvarium. Following some malfunctions, a multi 340i probe was used to take the temperature at the beginning of each operation. The missing temperature data were recovered from the daily temperature readings of the open circuit of the fish farm.
- The meteorological conditions were recorded for each experimentation day.

**3.5. Data processing**

The data processed concerned the number of lamprey individuals that managed to cross the whole ramp at the end of the experiment. This number was compared to the initial quantity of fish tested.

Chi-square tests were done on the percentage of individuals having successfully crossed the device. The significativity threshold was set at 5%.
4. RESULTS

4.1. Characterisation of the swimming of the brook lamprey

The observations made during the different tests allowed the swimming of the brook lamprey to be observed and characterised.

4.1.1. Mode of propulsion.

Like the Anguillidae, the lamprey moves by undulating its body. The frequency of these undulations as well as their amplitude depends on the speed conditions with which the individual is faced.

In a situation with a low current speed (<30 cm/s), the whole of the lamprey's body will undulate. The higher the speed of the current, the more the oscillations change. The anterior part of the body becomes more and more rigid until it is no longer undulating whereas the undulations of the posterior part become faster and faster and of lesser amplitude.

4.1.2. Swimming behaviour

Adult individuals always seek to move facing the current. In devices creating recirculations in the current, the lamprey will turn to face these inverse currents. The lamprey rarely swims close to the bottom. In general, it makes undulations in the water column, which often takes it to the surface and then brings it down again.

4.1.3. The special role of the sucker in crossing

During sustained and peak periods of swimming, lampreys have the particularity of being able to attach themselves to a surface using their sucker mouth in order to make what seems to be rest period. These rest phases can last up to twenty minutes. The lampreys will attach themselves to any kind of surface (riverstones, studs, Plexiglas, plywood,...), facing the current. Their head is then fixed while the rest of their body moves with the variations in the current.

The alternating of these phases of sustained swimming and resting allows them to compensate for their limited endurance (see next section) and to rest.

4.1.4. Swimming speeds

By placing the lampreys in different hydraulic configurations, we were able to establish some guide values in terms of swimming speeds, in particular for the critical speeds and maximum speeds. These were worked out essentially from observing the fish failing to cross, for which we carried out spot speed measurements.
- Maximum speed: in temperature conditions of 10 to 15°C, the brook lamprey seems not to be able to exceed speeds of 90-100 cm/s, or a value of the order of 6 to 7 L/s (L: length of the fish). All the configurations presenting speed values of >100 cm/s induced failures to cross.
- Critical speed: the critical speeds for the same temperatures ranges were found to be 70-80 cm/s,
- Optimum speed: the optimum speeds that constitute the separation between cruising swimming and sustained swimming are situated between 40-50 cm/s. Above 50 cm/s, the lampreys need to take rests by using their suckers to attach themselves to a surface.

We completed these observations with an estimation of the maximum swimming speed based on the Wardle formula (1975) which links swimming speed to the frequency of the oscillations of the caudal fin. Using the video recordings, it was possible to count the number of undulations made by a lamprey of a given size in a given period for current speed conditions of >70 cm/s.

$$\text{Max S} = (0.7\text{-}0.8) \frac{L}{2t},$$

where

- $\text{Max S} =$ maximum swimming speed,
- $L =$ length of the fish,
- $t =$ minimum time between two muscular contractions providing propulsion.

The results obtained give values varying between 8 and 12 undulations per second, or a time between 2 contractions varying between 0.05 and 0.075 s. A 15 cm brook lamprey therefore makes approximately 10 undulations a second, or an approximate time between two contractions of 0.06 second. The maximum speed thus obtained is of the order of 80 cm/s to 105 cm/s. This value does in fact seem to correspond to the maximum speeds measured for lampreys failing to cross. However, it cannot be considered as an absolute value, but only as an indication.

No data are available in the literature concerning the swimming capabilities of the brook lamprey. Occasional data do exist for juveniles of other species, in particular the Pacific lamprey (*Lampetra tridentata*) on the west coast of the United States (Moursund *et al.*, 2003; Dauble *et al.*, 2006; Schreck *et al.*, 2007). The authors state that above 70 to 80 cm/s of speed in front of grilles, lampreys cannot escape and remain stuck up against the obstacle. These authors determined a maximum swimming speed of 71 cm/s or a ration of 5.2 fish lengths per second and critical speeds of the order of 30-40 cm/s.

We can also compare our results with those obtained for eels, whose morphological characteristics and type of swimming correspond to those of the lamprey. For small sized subjects (young eels measuring 7.5 cm), McLeave (1979) provides maximum speeds under 55 cm/s or a value of the order of 7 times the size per second, which corresponds to that obtained for the lamprey. For individuals measuring 17 cm, Sprengel and Lüchtenberg (1991) give critical speed values of the order of 45-50 cm/s, which once again is relatively close to those observed in our experiment on lampreys for individuals of a slightly smaller size.

### 4.1.5. Endurance.

The lamprey's endurance is relatively low. For speed values close to the critical values (40-50 cm/s), the swimming time is less than 15 s on average. When the maximum speeds are reached, the time falls to values under 5 s. Between each movement, the lampreys use their sucker to fix onto a surface. Restarting is a key moment as it requires a high capacity for acceleration. If the lamprey is situated in an area with a strong flow (>80-100 cm/s), the probability of being carried back downstream is high.
4.1.6. Role of turbulence.

The observations made with numerous types of configuration have enabled us to get an idea of certain flow conditions that can pose problems for lampreys. Areas of water recirculation very often constitute traps for lampreys, which find it very difficult to get their bearings. Vertical flows also constitute difficult conditions for fish movement.


In 2007, 4 different configurations were tested with a single gradient (7.3%) and a flow without much variation (4.5-5.5 l/s (from 13.5 to 18 l/s/m of ramp width)). Fifteen tests were carried out with a total of 130 adult lampreys

4.2.1. Review of the crossings.

Over the 15 tests conducted, only 7% of the lampreys managed to reach the upstream end of the ramp and 13% remained inside the ramp at the end of the experiment. Successful crossing was statistically different for the 4 configurations (Chi-square test, p<0.05). Nevertheless, with only 1 repeat test for the ramp with an uneven bottom and regularly distributed stones and the chevrons, the validity of the results remains limited for these configurations.

![Figure 11: Comparison of lamprey crossings according to the different configurations tested.](image)

Crossing of the ramps equipped with partitions with vertical slots and slowing devices is very low (<3%), almost nil. In the case of the slowing devices, the lampreys got stuck at the point of the 3rd chevron. For the stone sills, on average 1 lamprey in 5 managed to cross the 4 m of the ramp. For the test done with the uneven bottom and the regularly distributed stones, the result is very fragmentary with only 4 lampreys used in the test, of which 2 were in poor condition and with, in the end, only one individual crossing the ramp.

In terms of behaviour, the tests enabled us to observe the lampreys’ swimming and their mode of progression. In all the configurations, the lampreys made short movements for 2 to 5 s before fixing onto something. They are capable of crossing stone sills through crevices.
In the case of the partitions with vertical slots, they were highly perturbed by the recirculations of water in the different tanks. After failing to cross at one of the slots, the lampreys were systematically ejected far downstream. They did not manage to attach themselves with their suckers.

### 4.2.2. Hydraulic characteristics in the ramp

<table>
<thead>
<tr>
<th>Configurations</th>
<th>Hauteur d'eau (cm)</th>
<th>Vitesse maximale (fente, échancrures, pointe chevrons cm/s)</th>
<th>Puissance dissipée volumique (watt/m²)</th>
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<tr>
<td>Seuils blocs</td>
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<td>65</td>
<td>77</td>
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<tr>
<td>5 cloisons</td>
<td>14</td>
<td>100</td>
<td>105</td>
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<tr>
<td>7 cloisons</td>
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<td>Ralentisseurs</td>
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<td>70</td>
<td></td>
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<tr>
<td>Rampe rugueuse</td>
<td>5.5</td>
<td>55</td>
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</table>

Table 2: Average hydraulic characteristics of the different configurations tested.

Depending on the configurations, water depths varied from 5.5 to 18 cm. The maximum speeds measured either at the weirs, the slots, at the point of the chevrons or between the stones varied from 55 to 100 cm/s. Depending on the configurations, there will be differing amounts of turbulence, which limits the validity of the speed value measured.

![Figure 12: Comparison of lamprey crossings with maximum speed values measured in the ramp according to the different configurations tested.](image)

The crossings observed are linked to the hydraulic conditions in the ramps. Speed values above 70-80 cm/s are difficult for lampreys to cross. Above 1 m/s, crossing is impossible. The presence of water recirculations also handicaps the fish. In terms of power loss, it seems that it is necessary to remain within values under 80 watts/m³. The water depths may remain low (<10 cm).
4.2.3. **Review of the 2007 experiments.**

The 1st tests carried out in controlled conditions showed:

- that brook lampreys made numerous crossing attempts faced with an obstacle, thus confirming their desire to move in the adult stage,
- that the species’ swimming capabilities were limited, imposing speed values in crossing structures of <70-80 cm/s,
- that areas of current recirculation were detrimental to crossing,
- that the lampreys did not need resting areas to cross an obstacle, they use their suckers to attach themselves to a surface when conditions become difficult.

Based on these 1st tests, it seemed relevant to continue the tests, concentrating on configurations with uneven bottoms and without current recirculations.

4.3. **Experiments conducted in 2008.**

The combination of all the configurations and flow ranges led to 72 tests being carried out for a total of 624 individuals.

In total, including all the configurations, 136 individuals or 22% managed to cross the ramp and 78 or 12% had only covered a part of the ramp at the end of the experiment.

4.3.1. **Influence of the time of day.**

In order to optimise the conditions in which the tests were carried out and place the lampreys in the most relevant situation in terms of movements, we first of all checked the lampreys' preferred period of movement, day or nighttime. The tests were done 2 gradients (5% and 8%) and were repeated for each gradient with the same configurations and the same flow ranges.

Globally, the crossing for the same configurations and the same gradients were significantly higher in the daytime than at night (on average 17% effectiveness in the daytime and 10% at night).
Figures 13 and 14: Comparison of lamprey ramp crossing in the daytime and at night for (a) a 5% gradient and (b) an 8% gradient.

The differences are very high for the Evergreen studs with a level of effectiveness of 44% on average for the daytime tests compared to only 10% at night. For the ramps with uneven bottoms also tested with 2 gradients, the overall effectiveness levels were low (<7%) with a slight difference between the daytime and the night (6.4% on average in the daytime compared to 4.3% at night). Only the tests with the studs did not show a differences between the 2 parts of the day.

This 1st series of tests concluded that lampreys are markedly more active in the day than at night. For the rest of the experiments, we therefore compared flows, substrates and gradients in daytime tests.

These observations do not really conform with current knowledge on the species, the migratory phenomenon Lampetra planeri seeming to be essentially nocturnal (Malmqvist, 1980; Hardisty and Potter, 1971) even if at the end of the season, it is possible to observe individuals migrating during the daytime (Malmqvist, Ibid.). However, for certain authors, adult brook lampreys are abandoning all forms of photophobia and reproducing on sunny days (Kottelat and Freyhof, 2007). As a result, the existence of better crossing diurnal capabilities would appear logical. It is also possible that the lunar phase has an influence. The nighttime tests were essentially carried out on nights when there was a full moon with quite a lot of light. Kelly and King (2001) note that the migration of this species favourably influenced by low luminosity. Similarly, Asplund and Sodergren (1975) in Malmqvist (1980) demonstrated a correlation between lunar activity and the migration of the river lamprey (Lampetra fluviatilis). It is therefore possible that the luminosity provided by a virtually full moon could have had a negative influence on the ascending movements of the brook lampreys tested.

**4.3.2. Definition of a gradient limit value.**

In terms of the possibility of adapting obstacles, the maximum gradient of the crossing device is an important factor to know before deciding the main characteristics of the device and the types of obstacles liable to be equipped with it. Indeed, a crossing structure with a 10% gradient means a length of 10 m for every meter of difference in the level of the obstacles. Bearing in mind that the objective for a species such as the brook lamprey is essentially to equip obstacles on small water courses (often <5m wide), it would seem unrealistic to envisage crossing devices that are too long in relation to the width of the river. It is therefore
essential to find the best compromise in terms of the maximum gradient providing both good crossing effectiveness and limited occupation of the space. To do this, we sought to discover the maximum acceptable gradient by testing on 2 types of substrates and 2 or 3 flow values a gradient of 8% and 12%.
Figures 15 and 16: Comparison of brook lamprey crossings for two identical substrates ((a) studs and (b) brushes) according to the gradient and the different flow ranges.

For studs, lamprey crossing is high for low flow values (<10 l/s), whatever the gradient. On the other hand, for brushes, crossing rates were distinctly lower at 12% than at 8%, whatever the flow.

A gradient >10% therefore presents significant crossing limits and possibly only allows use at low flow values (<25 l/s/m of width).

We therefore decided to continue the experiments on substrates and flows whilst limiting the ramp gradient values to 8% maximum.

4.3.3. Definition of the optimum substrate/flow configuration.

In this series of experiments, we sought to discover the substrate/flows pairs providing the best crossing for lampreys for a given gradient value (8%).

Crossings of the whole of the ramp by brook lampreys differed significantly (Chi-square test, p<0.05), both between types of substrate and flow values.

Whatever the flow passing through the ramp, the brushes constituted the most effective substrate (average of 59% of lampreys reaching the upstream tank, compared to 42% for the Evergreens, 40% for the studs and 9% for the ramps with an uneven bottom and regularly distributed stones). The ramps equipped with stone sills were not crossed in any of the tests carried out, even with low flow values.

As regards the flows, the crossings decrease very markedly when the values are over 15 l/s or more than 37.5 l/s per metre of ramp width. For the 3 most effective substrates (brushes, Evergreens, studs), the crossings go successively from 91% to 55% then 20% for unit flows of 10 l/s, 15 l/s and 20 l/s/m.
With the exception of the stone sills where the majority of the lampreys were stuck in the ramp at the end of each test (with over 80% of the individuals in the downstream quarter), few lampreys remained in the device at the end of the experiment, with failures to cross in most cases involving a return to the downstream cage. It should also be noted that the Evergreens were tested quite late in the season (from 14 May 2008 on) when the lampreys were already showing signs of weakening. We can therefore suppose that at the beginning of the migration period, the results would be more significant and probably closer to those of the brushes.

4.3.4. Test on a configuration with a 5% gradient.

As well as the previous experiments, tests were carried out on a 5% gradient with Evergreen, stud substrates and a ramp with an uneven bottom and regularly distributed stones.

Globally, crossing with a 5% gradient are not statistically different to those observed at 8% (Chi-square test, p<0.05) (22% of crossing compared to 29% of crossings for the same substrates and the same flows).

On the other hand, in terms of flow ranges, the situation is different. Crossing rates are significantly lower for flows below 15 l/s with a 5% gradient than with an 8% gradient. On the other hand, they are higher for higher flows (>15 l/s).

As for the 8% gradient, crossing are globally similar for the Evergreens and the studs with the exception of situations with low flows (<10 l/s) where the Evergreens provide better considerably crossing rates than the studs (61% compared to 40%).

4.3.5. Hydraulic conditions in the different tests.

Current speed and water depth measurements have enabled us to partially characterise the flow conditions of the different configurations tested. We have used these measurements to confront them with the lampreys' swimming capabilities and establish relationships between flow/speed/water depth according to the configurations and the gradient.
Figure 19: Changes to current speeds in the ramps for a 5% gradient according to the flows and the type of substrate.

Figure 20: Changes to current speeds in the ramps for an 8% gradient according to the flows and the type of substrate.

The average speeds in the ramps change significantly depending on the unit flow and type of substrate. For both gradients, it is the ramps with studs that have the highest speed values, whatever the flows. The critical speeds for the lamprey (70-80 cm/s) are reached at flow values close to 45 l/s/m for the Evergreens and 35 l/s/m for the studs.
On the other hand, the average speeds remain lower than 50 cm/s in the ramps with uneven bottoms equipped with scattered stones. Globally, the average speed value can be approached using the Manning Strickler formula with a roughness coefficient of 13.5 for the Evergreens and 15 for the studs.

**Figure 21: Changes to water depths in the ramps for a 5% gradient according to the flows and the type of substrate.**

**Figure 22: Changes to water depths in the ramps for a 8% gradient according to the flows and the type of substrate.**

Water depths also change according to the flows, the gradient and the type of substrate. The highest water depth values are observed with the ramps with uneven bottoms with regularly distributed stones. In the other devices, we observe relatively similar changes with values of 5 cm for unit flows of 25 l/s/m and 10 cm for flows of more than 60 l/s/m of ramp width.
If lamprey crossings are compared with the average speed values, the key role of the flow speed conditions in the devices is confirmed.

Figure 23: Lamprey crossings according to the average speed value in the ramps for the different gradient and substrate configurations.

Globally, whatever the configuration, the crossings rate falls considerably for average speed values > 70 cm/s. The 12% gradient also presented lower crossability in spite of speed conditions compatible with the lamprey’s capabilities.

The flow passing upstream of the Evergreen ramp can be evaluated by the following formula:

\[ Q(\text{l/s/m}) = 0.37 \times \sqrt{2 \times 9.81 \times h^{1.28}} \]

with

- \( Q \): the unit flow passing through the ramp in l/s/m of ramp width
- \( h \): the upstream head on the Evergreen studs in cm
4.4. Crossing of other species.

Crossing tests were also carried out with other species characteristic of headwater streams, namely the chub, brown trout, loach and minnow. We will only present the results of the experiments conducted using Evergreen substrates.

4.4.1. The chub.

We used chubs captured by electric fishing in the River Yonne close to the site of the experiments. The average size of the chubs was 74.3 mm (±27 mm) corresponding to at least 3 different age groups (1 year, 2 years and 3 years). As for the lampreys, the chubs were placed in a cage downstream of the ramp.

![Figure 25: Crossing of a ramp with an 8% gradient equipped with Evergreen by chubs according to the flow value.](image)

The chubs showed quite a strong impulse to ascend the ramp. The crossing rates fell as the flow increased (Chi-square test, p<0.05). For the low flows (<15 l/s or 37.5 l/s/m of width), crossings were over 60%, and even 80% for very low flows. They fall very significantly from 15 l/s to become anecdotal at 20 l/s or 50 l/s/m of width.

For a 5% gradient, the crossing rate was higher (25%) up to 30 l/s or 75 l/s/m of width. We did not observe any significant effects of the size of the fish either in terms of the impulse for movement, or in terms of successful crossing. Only fish with a size of <50 mm never managed to reach the upstream tank, which in principle corresponds to young 1-year old individuals.

The chub moves in successive “jumps”. It swims between the studs and rises rapidly to the surface of the water, then comes down and sits on the bottom. Crossing takes place in speed ranges of the order of 80-90 cm/s, which corresponds to the species’ swimming capabilities (Tudorache et al., 2007) tested in the fluvarium. During their rest phases, chubs sit on the bottom and can stay in place even in high speed values (>1 m/s) thanks to their pectoral fins.
4.4.2. *The brown trout.*

As for the chub, tests were carried out with young trout from the fish farm with an average size of 99 mm, corresponding to the year’s fry and a few 1-year old individuals. The experiments were done with the Evergreen substrates and the flow ranges tested for the brook lamprey at temperatures varying from 12 to 15.5°C.

![Figure 26: Crossing of a ramp with an 8% gradient equipped with Evergreen by brown trout according to the flow value.](image)

Small brown trout (100 mm on average) did not have any difficulty crossing the ramps with the 8% gradient equipped with Evergreen substrates and supplied with flows of less than 35 l/s/m of width. The crossing rate remained significant for these small individuals up to 50 l/s/m of width (50% passages upstream).

4.4.3. *The stone loach and the minnow.*

As well as the tests carried out with chubs and trout, we conducted experiments with two other species that exist alongside the brown trout in headwater streams, namely the stone loach and the minnow. The fish were caught by electric fishing in the River Yonne close to the site of the experiments. The size of the minnows varied from 60 to 85 mm, that of the loaches from 65 to 85 mm. Here we present only the configuration with an 8% gradient equipped with Evergreens.
The behaviour of the two species studied was relatively similar. The crossing rates fall significantly with the value of the flow passing through the ramp (Chi-square test, p<0.05). For the stone loach, the effectiveness of the ramps remained high with a rate of over 70% passages upstream for flows up to 50 l/s/m of width. For the minnow, the effectiveness fell considerably from 35 l/s/m of width.

The two species do not have the same swimming behaviour. The stone loach, like the chub, swims close to the studs whereas the minnow swims much more in the open water above the Evergreens.

4.4.4. Conclusions on the crossing of other species.

The tests carried out with the Evergreen configuration with an 8% gradient gave a high crossing rate for all the species colonising headwater streams, namely the chub, brown trout,
stone loach and minnow. As for the brook lamprey, increasing the flows reduced the effectiveness of the crossing devices. For all these species, it is possible to pass through flows of the order of 35 l/s/m of ramp width whilst guaranteeing a good degree of crossing effectiveness of the species.

5. CONCLUSIONS

The experiments carried out in controlled channels enabled us to get a better idea of the crossing capacities of adult brook lampreys and thus to define the dimensioning criteria for devices specific to this species. Faced with an obstacle, adult brook lamprey make crossing attempts. Their swimming capabilities remain limited with maximum speeds of the order of 70 to 80 cm/s over periods of 5 s at the most and critical speeds close to 40 cm/s over periods of 15 s. Thanks to their mouth sucker, lampreys are able to attach themselves to any surface, which enables them to alternate swimming and rest phases. Among all the devices tested, certain configurations provide a very good level of crossing effectiveness. This involves a ramp with a maximum gradient of 8% equipped with uneven substrates regularly distributed and supplied with a maximum flow of 25 to 30 l/s per metre of width. The substrates may consist of studs 4 to 6 cm in height. The depth of the water above the studs must be between 1 and 1.5 times the height of the studs inclusive. Configurations of the type with successive pools with slots or a ramp with an uneven bottom with regularly distributed stones are not favourable due mainly to current recirculations between the stones or in the pools. These recirculations strongly interfere with the progress and orientation of the lamprey. The devices to provided at obstacles may therefore consists of an invert whose gradient will not exceed 8%, covered with a regular high-density substrate providing a flow with quite low turbulence. In order to provide favourable crossing conditions for different water course flows, it is possible to provide a lateral dip in the invert (10-15% maximum). Concerning the other headwater stream species, the tests enabled us to check that the ramps favourable to lampreys also allowed chubs, minnows, stone loaches and small brown trout (<100 mm) to cross, in the same flow ranges.
<table>
<thead>
<tr>
<th>Device</th>
<th>Crossability</th>
<th>Practical use</th>
<th>Durability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evergreen studs</td>
<td>Good for all the species.</td>
<td>Use in a wide context. Low cost. Can be crossed by vehicles. Not very attractive. Requires the gaps to be filled for the lamprey.</td>
<td>Solid device, durable over time. Low sensitivity to clogging.</td>
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<tr>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>R. with uneven bottom</td>
<td>Effective for trout, minnows, chubs.</td>
<td>Not easily crossable by the lamprey. Close to natural conditions, use for crossing obstacles, but cannot be crossed by vehicles. Dimensioning requires precise criteria.</td>
<td>Solid device, durable over time, not very sensitive to clogging.</td>
</tr>
<tr>
<td>Plastic studs</td>
<td>Good for the different species.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
<tr>
<td>Brushes</td>
<td>Effective for the lamprey</td>
<td>Not easily crossable by the chub.</td>
<td>Highly sensitive to clogging and risks being damaged by logjams.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slowing devices</td>
<td>Effective for the other species? (lack of repetition).</td>
<td>Not easily crossable by the lamprey.</td>
<td>Sensitive to clogging for gradients &lt; 8%.</td>
</tr>
<tr>
<td>Vertical slots.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stone sills</td>
<td>Effective for the pelagic species (trout and minnow).</td>
<td>Not easily crossable by the lamprey. Design that might be low-cost and quick to use depending on the context.</td>
<td>Solid device, durable over time depending on its design</td>
</tr>
</tbody>
</table>

Table 3: Summary of the characteristics of the different substrates with a view to their use in a natural environment.
6. EXAMPLE OF A CROSSING DEVICE SUITED TO THE BROOK LAMPREY

As part of the actions under the LIFE programme, a sill (height 80 cm) and an agricultural ford have been built on the Valezin stream, a tributary of the Valouze, in the low Jura mountains (fig 29), on the basis of the dimensioning criteria defined thanks to the experiments in a controlled channel. Situated 200 m upstream of the confluence with the main river, this sill constituted an obstacle impossible to cross for the brook lampreys present at the foot of the structure and absent upstream. It was not possible to remove the sill due to problems with the stability of the upstream banks alongside a main road, so the only possible solution was to build a crossing device. Based on the topographical study and knowledge of the variations in the water levels up and downstream of the sill, the device was dimensioned to allow the fish fauna present in this basin to cross (brook lamprey, trout, minnow, chub, loach).

![Figure 29: Agricultural sill before a adaptation](image)

The device built consists of a ramp with an 8% gradient equipped with Evergreen studs (fig 30). A 15% lateral dip has been provided (fig 31) in order to offer speed and water depth ranges favourable to the largest number of species, whatever the flow values passing through. The maximum head at the lowest water level upstream of the ramp was fixed at 7 cm from the top of the Evergreen studs.

An intermediate pool has also been created to give species other than the lamprey a resting area (fig 30).
Figure 31: Cross section of the Valezin ramp.

Photographs of the ramp when the water was let in

Monitoring should be carried out during the migration period as well as counting of the fish spawning areas upstream of the structure in order to evaluate the effectiveness of the fish pass.
BIBLIOGRAPHY


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