Behavioural Experiments on the Design of Downstream Fish Passage Facilities for Potamodromous Species

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Abstract: *Whereas upstream fish migration facilities are rather well established, there remains a lack of efficient downstream fish migration facilities. Following the main flow most fish pass through the turbines which results in major damages and mortality rates. The main challenges of downstream fish migration are to prevent fish from passing through the turbines and furthermore enable them to find the entrance of the downstream passage. A conceptual solution was investigated in the laboratory of Hydraulic and Water Resources Engineering of Technische Universität München. A life size experiment with potamodromous species was conducted to study the fish behaviour at the intake of a hydraulic structure. In a large open air lab flume the possibilities to shield the fish from crossing through a screen and lead them to a surface bypass with an inclined trash rack was examined. Different trash rack inclinations and bypass designs were tested.*

Keywords: *ecological connectivity, fish downstream migration facilities, hydro power plant, fish experiment, fish behaviour*

1 INTRODUCTION

Hydraulic constructions may seriously interfere or completely obstruct the ecological continuity and particularly the fish migration in a water body. To maintain a sustainable fish population, a safe passage for migrating fish across stream barriers is essential. Fish passage facilities, as for example bypass rivers, fishways or fish passes, are developed to minimize the environmental impact of dams. However, while there has been a significant progress in the design and implementation of fishways for upstream migration, downstream fish passages have not been sufficiently studied. The downstream migrating fish mostly follow the main stream and thus pass through the turbine, if not prevented by a fine enough trash rack with adequate velocities. Thus fish injury and mortality depending on the power intake structure, the fish size and the turbine type may occur (Holzner, 2000). Therefore the principle of a fish downstream facility is first to stop the fish before the turbine with a physical barrier (screen / trash rack), to guide them to a bypass and finally to bring them downstream safely. Actually the second point turned out to be the most challenging. Some facilities show poor efficiency because fish cannot find the entrance and swim towards the turbine or are pressed at the screen after weakness and unsuccessful search. Thus concepts are needed which assure respectable attractiveness. The most direct method to investigate this is the observation of live fish.

In the Laboratory of Hydraulic and Water Resources Engineering of the Technische Universität München an experiment with potamodromous fish was conducted to study fish behaviour at the simulated intake of a hydropower plant. The model consisted of a screen inclined to the horizontal to shield fish away from the turbine and lead them to a surface bypass. Different inclinations of the screen and different bypass configurations were tested to determine the best efficiency of the fish downstream passage. The objective of the experiment is to optimize a facility which both protects fish from injuries at the turbine and provides an efficient passage downstream.

2 METHODOLOGY

2.1 Fish monitoring

During the summer of 2010 a series of experiments with live fish were conducted. Three species were studied: barbel (*Barbus barbus*), chub (*Squalius cephalus*) and nase (*Chondrostoma nasus*). The swimming behaviour and habitat preferences of these species differ, thus the used species set represents a main part of the ecological spectrum of fish in the barbel region. Barbel and nase are typical bottom-dwelling species. Barbel prefers shelter and deep water especially during nighttime, whereas nase rather selects shallower and less structured bottom also during nighttime. As a contrast, chub strongly prefers structured habitats such as wood, overhanging vegetation or riprap. Barbel (number of fish (n) = 63, mean total length (tl) 344 ± SD 123 mm), nase (n = 105, mean tl 325 ± SD 60 mm) and chub (n = 69, mean tl 290 ± SD 57 mm) were caught in the Danube using electrofishing equipment. A Passive Integrated Transponder (PIT) tag was injected into the body cavity of each fish. The PIT is a biotelemetry method which allows monitoring of the fish passage. The chip provides a unique code which is read out when the fish pass through an antenna. The PIT (12 x 2 mm) is passive and does not need any power supply. Four antennas (61 x 61 cm) were connected to a computer which recorded the passage of the fish during the whole test duration. The antenna delay was set to four minutes (only one signal per fish in four minutes was recorded) with regard to data storage and processing. The fish were kept and fed in two pools (2000 x 2000 x 700 mm) with a constant supply of fresh water from the Isar River in order to adapt them to the water condition used during the tests.

2.2 Experimental setup

The experiments were conducted in an open air lab flume of 220 m length, 2 m depth and 1.25 m width. It was supplied with water from the Isar River. An inclined screen with a bar clearance of 2 cm was installed in the middle of the test section. Four inclinations were tested: 20°, 30°, 45° and 70° to the horizontal (see figure 1). At the top of the screen a horizontal deck separated the flow towards the turbine and the flow towards the bypass (see figure 2). About 10 meters upstream and downstream of the inclined screen two grids were installed in order to keep the fish in the test section and stop floating debris coming from upstream. Four PIT antennas were installed: one at the top of the screen (1), one at the end of the bypass (2) and two superposed (3 and 4) below the bypass which represents the turbine location.

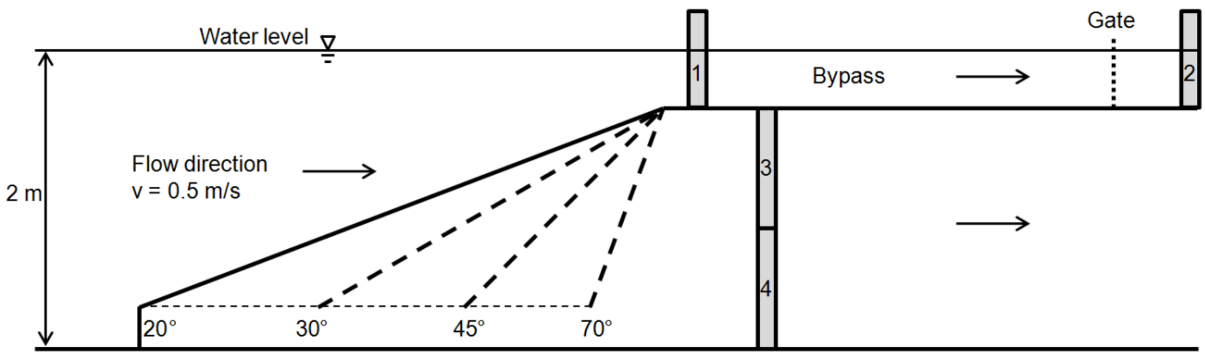

Figure 1 Longitudinal section of the experimental setup: PIT antennas marked grey

In the first series of experiments the four inclinations were tested. For each of these tests, the bar clearance of the screen was 2 cm. A closed gate upstream of antenna no.2 prevented a fish passage into the downstream while the velocity in the bypass is nil and the water depth is 27 cm. The objective of this first series was to investigate which inclination of the screen provides the best guidance into the bypass entrance. In the second series, different configurations of the bypass were tested to allow an efficient passage of the fish to the downstream. The inclination of the screen of 30° and the bar clearance of 2 cm were kept constant. Four configurations were tested (see figure 3). In the first configuration the gate between antenna 1 and 2 had an overflow of 5 cm depth. The velocity in the bypass was 0.25 m/s. In the second test the overflow depth was 10 cm but only on half of the gate width in order to obtain a velocity of 0.25 m/s. The third test consisted of a vertical slot with 25 cm width on the right hand side. The last test was done with two vertical slots, each 40 cm wide. The velocity before the first slot was again 0.25 m/s (see figure 3).

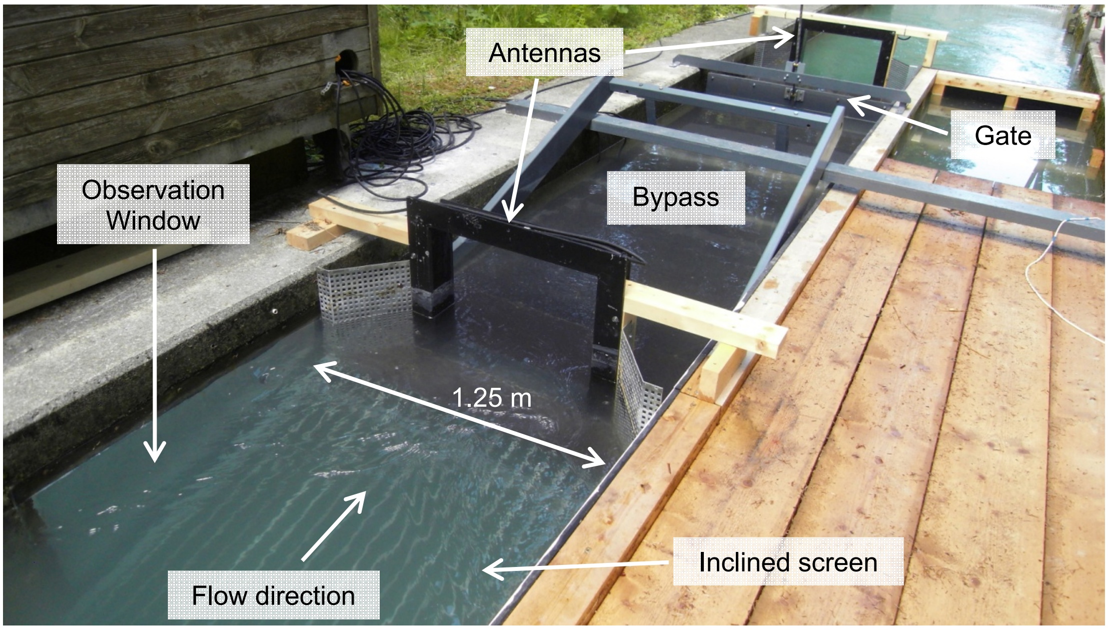

Figure 2 Photo of the experimental setup

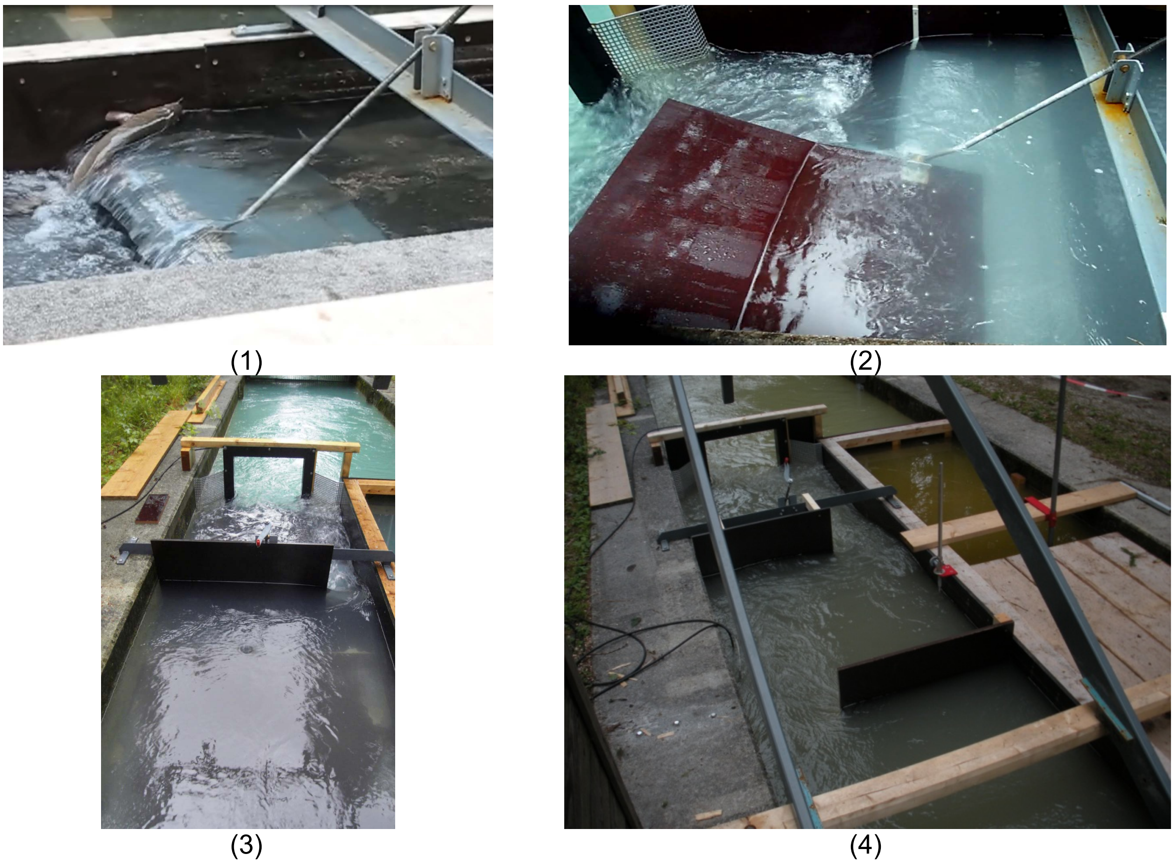

Figure 3 Bypass configurations

2.3 Experimental procedure

Each test was started between 7 and 8 o'clock a.m. by putting the fish in the head water of the test setup, about 10 m upstream of the inclined screen. Each time 50 fish per species with representative size distribution were employed. The velocity at the screen was 0.5 m/s and the water depth was 2 meters in the channel and 27 cm in the bypass (see figure 1). Water turbidity (by means of a Secchi disk) and velocity (by Ott-propeller) were measured at the beginning and at the end of the test. The water temperature was recorded during the whole test duration. Each experiment was conducted 24 hours during which the antennas recorded the fish passage.

3 RESULTS AND DISCUSSION

3.1 Fish behaviour

Contrary to a pretest in 2009 with trout farm fish (Cuchet *et al*, 2009), the wild fish showed intense activity migrating downstream and a specific diurnal pattern. The fish were mostly active from the afternoon to the evening, which coincided with the water temperature increase. Differences between the three species were observed: barbel and chub showed more activity whereas most of the nase stayed upstream. There can be no conclusion drawn whether this was due to their general lower level of activity or a result of their shy behavior, turning around at the base or the middle part of the screen where the fish movements could not be detected. In nature, the factors causing downstream migrations are in general season, phase of the moon, water turbidity grade, discharge change, light conditions and water temperature change (Schwevers, 2000). In the experiment, the fish were rheoactive and swam most of the time head upstream when the velocity is different from zero. Nase and especially barbel swam in swarm whereas chub showed rather individual behaviour.

3.2 Data analysis

13 tests were conducted, the database for each test consisted of 864 to 14780 fish signals. Each signal includes date, time, antenna number and individual code. Based on these data, identification of fish species and size are done. As the fish pass many times through the antennas, a statistical analysis is required, which is still under progress. In the following results only the first passage of each fish was taken into account. An active fish is considered as a fish which was detected at least once at any of the four antennas.

3.3 Screen inclination

The number of fish which pass above the screen or through the screen in function of the screen inclination is represented in figure 4. Although the number of fish for each test was constant ($n = 150$), the number of detected fish varied. With a rather vertical inclination of the screen ($\alpha = 70°$) fewer fish were detected in comparison with flatter angles. Thus an almost vertical screen seems to be repellent for fish and does not forward guidance to the surface bypass. For flatter screen inclinations about 80 fish from 150 fish were detected. Between 20, 30 and 45° there is no significant difference concerning the fish finding the passage above the screen, but the numbers of fish which pass through the screen clearly increase with the inclination. The 20° screen inclination is the most efficient to avoid the fish passage through the screen and to guide them to the top. Only one small fish (length 190 mm) passed through the 2 cm bar clearance at this inclination.

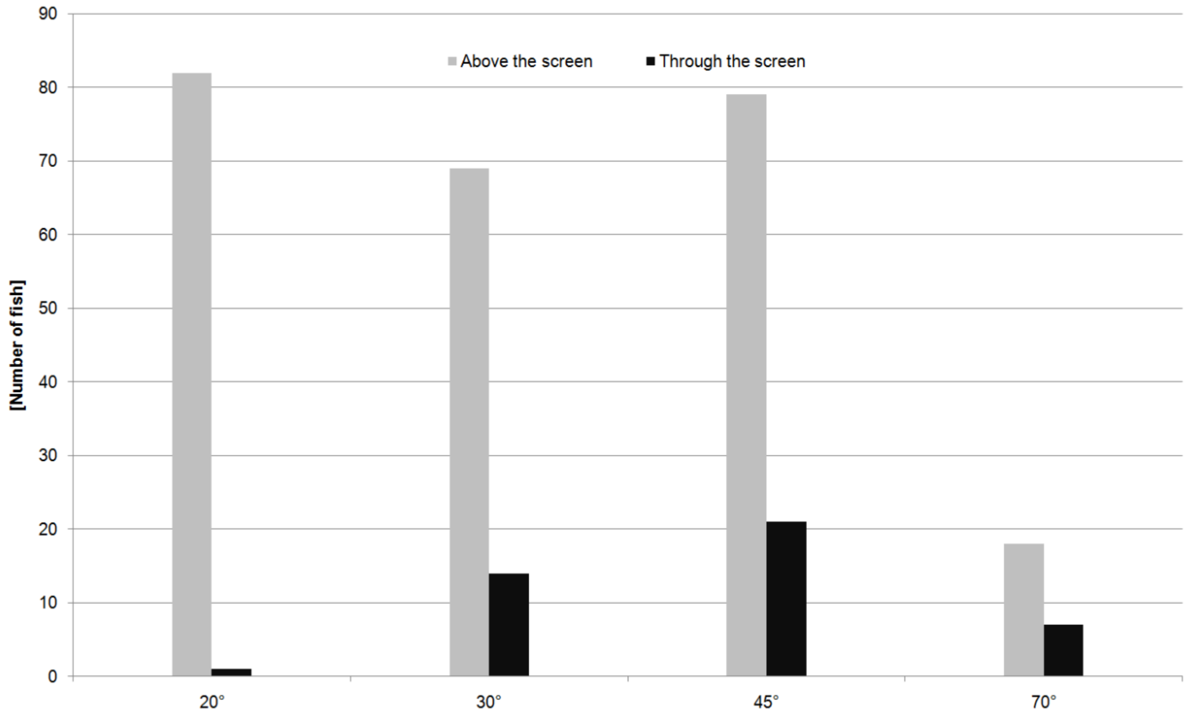

Figure 4 Screen inclinations, bar clearance 2 cm

3.4 Bypass configurations

Figure 5 shows the results for the different bypass configurations tested. The absolute downstream passage efficiency is defined by the following formula:

$$E_d = \frac{p}{n} \tag{1}$$

where p is the number of fish which found and used the downstream passage (detected in antenna 1 and 2) and n is the number of active fish; the fish which were detected at least one time at any of the four antennas. To characterize the efficiency of the bypass configuration with regard to the efforts it takes the fish to pass downstream, the attractiveness parameter a is introduced:

$$a = \frac{p}{n_1} \tag{2}$$

where n_1 is the total number of passages through antenna 1 of all fish which got through antenna 2. If the passage is attractive a value tends towards 1 whereas a smaller value of a indicates that the fish was searching for a long time passing many times through antenna 1 before reaching antenna 2. Because of the 4 minutes sampling interval it is not possible to calculate the exact duration the fish needed to pass between antenna 1 and 2. Nevertheless, the number of signals gives a representative measure.

Both gate overflow constructions showed about 50 % downstream passage efficiency. Raising the overflow depth from 5 cm to 10 cm while reducing the overflow width to maintain constant velocity yielded better results with regard to the attractiveness (12 % for 10 cm instead of 8 % for 5 cm). As also implied by video observation of the fish traversing the gate, the higher gate overflow depth provided a much more comfortable passage which would explain the results.

The investigated vertical slot configurations showed total efficiencies of 65 % for one slot and 75 % for two slots. The attractiveness was 18 % for the first setup and 43 % for the second. Thus the compact flow in the vertical slot configuration seems to favor the efficiency compared to the gate configuration. Furthermore the bypass with two vertical slots performs remarkably advantageous for downstream passage. This seems a result of the more moderate flow in the slot areas due to the lower water level difference.

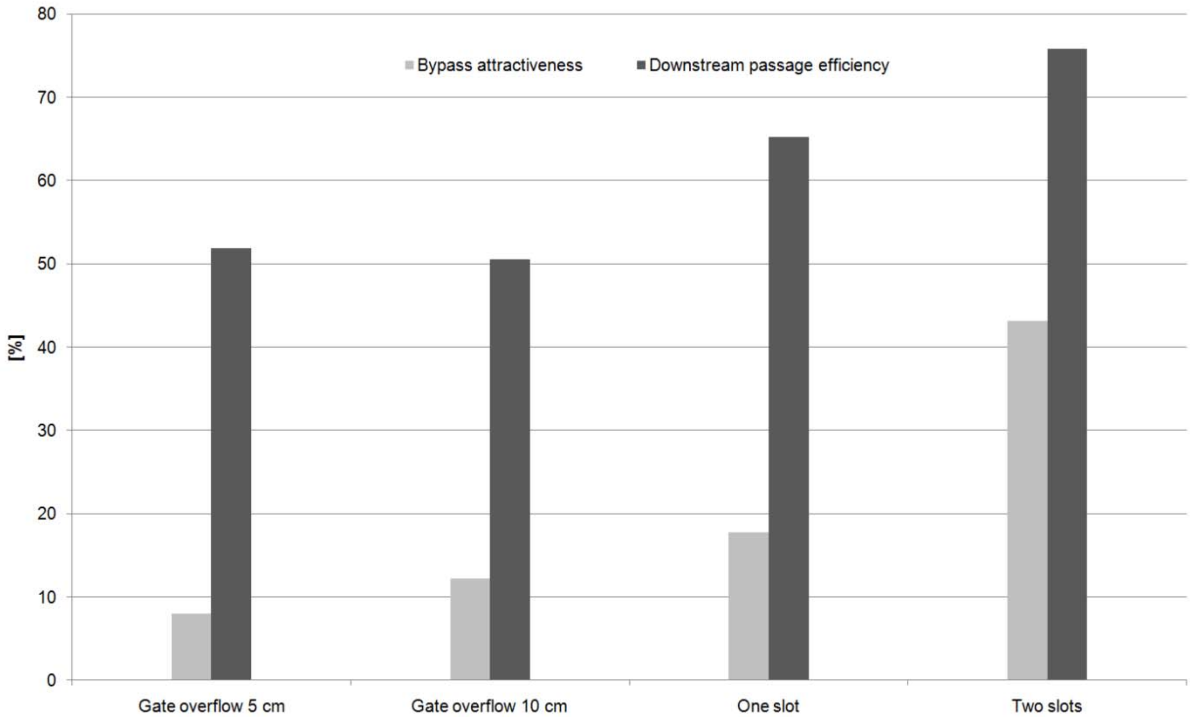

Figure 5 Attractiveness and efficiency of the bypass configurations

4 CONCLUSION

The live fish experiment presented yielded promising results concerning the development of effective fish downstream migration facilities for potamodromous fish. The observation of the fish behaviour at an inclined screen with 2 cm clearance proved that this setup can protect fish in the size longer than 190 mm from entering the turbine and consequently leading them to a surface bypass. The variation of the inclination angles confirmed that a larger angle of the screen against the vertical does effectively improve fish protection and guidance.
Furthermore the experimental setup was combined with different types of bypass configurations and the resulting efficiencies and attractiveness were investigated. A setup with two vertical slots was found to be the best arrangement for quick and successful downstream migration. This is likely due to the continuous ground level and the compact and moderate flow in the slots. This suggests that a bypass with more moderate flow or no constrictions can provide downstream passage more efficiently. Besides, the results obtained valuable expertise concerning large scale tests with live fish under controlled but realistic laboratory conditions (controlled discharge and water depth, water from a natural river flowing in a large scale open air lab flume) could be acquired. The feasibility of such experiments especially for developing and improving prototype fish facilities could be proved. As demonstrated for the case of the nase, species behave differently and therefore it is essential to investigate their different requirements.

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