Fish migration in polder areas - evaluation of a de Wit fishpass

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ABSTRACT: As water conservation is an important item in the management of polder areas during a part of the year, water courses in these areas contain many regulating constructions. Such constructions can affect the free movement of migrating fish to and from these areas. Problems can be solved by either removing the barriers or providing fish passage facilities. A possible solution for these areas is the so called de Wit fishpass, which was derived from a classical vertical slot fishpass. Experimental research has been done in order to evaluate the efficiency of this fishpass under several laboratory conditions. The aim of the research was to determine whether stream velocities and construction length were influencing the successfull clearing of the fishpass for several lowland fish species. Final goal was to present design rules for constructing successfull de Wit fishpasses on the field.

1 INTRODUCTION

1.1 *Setting of the research*

In order to meet the requirements of the Benelux Decree concerning Fish Migration all physical obstructions for fish migration in every hydrografic basin in Belgium, The Netherlands and Luxemburg should be removed by 2010. This can be done by really removing the barriers. Another solution is to provide fish passage possibilities. This requires that the construcions are adapted to the biological needs of local fish fauna. One way of checking this condition is monitoring after construction. Another way is to test the construction in advance.

In 2000-2001 extended research has been done to evaluate a de Wit fishpass. The research was carried out by the Hydraulic Engineering Laboratory and Hydrological Research Division, in close collaboration with the Institute of Forestry and Game Management, which both are part of the Ministry of Flanders (Belgium).

1.2 *Working principles of a de Wit fishpass*

The de Wit fishpass has recently been developped by making some adaptations to a classical vertical slot fishpass. The fishpass consists of a series of chambers separated by walls. The vertical slots have been replaced by rectangular orifices close to the bottom. The orifices are alternating on the left and right side of the fishpass and are completely submerged. Important parameters are the overall waterlevel difference H_{tot} (m) and the number of walls T (-). These parameters are determining both for limiting stream velocities - important for fish passage - and regulating discharges - important for water management. The working principles are clarified by the following simple formulas:

$$V = C_v \times \sqrt{2 \times g \times \frac{H_{tot}}{T}} \tag{1}$$

$$Q = C_D \times V \times A \tag{2}$$

where V = mean velocity in the orifice (m/s); C_V, C_D = coefficients for friction losses (-); g = gravitational acceleration (m/s²); Q = total discharge (m³/s); and A = orifice area (m²).

From formulas (1) and (2) it can be seen that at a given overall waterlevel difference H_{tot} the number of walls T is a crucial factor in regulating the stream velocity V and hence the discharge Q: a higher T will result in a lower V. On the other hand a higher T also implies higher construction costs. Hence a realistic design will have a number of walls between $T_{optimal}$, causing no problems for fish migration and $T_{critical}$, with stream velocities that become critical to certain fish (species) (see also section 1.3).

1.3 *Goals of the research*

For this research project three goals were formulated:

1. check whether a de Wit fishpass is a suitable solution for migration of fish species typical for water courses under considaration, namely low lying (polder) areas;
2. determine the impact of stream velocities and total length of the construction, exploring critical borders/values for these parameters;
3. formulate design criteria for construction a de Wit fishpass on the field.

2 METHODS

2.1 *Fish species*

In this research six fish species were tested on their capability of clearing a de Wit fishpass under several circumstances. The species were chosen so that a typical composition of the ichtyofauna in polder areas was represented. Another selection criterion was the availability of fish at the fish farm. Table 1 presents the fish species used in the experiments.

The individual fish were divided into two groups, to separate the carnivorous species from the non-carnivorous species. Further a replica of each group was used for statistical reasons, so there were four groups in total. The groups were stocked in a flume apart from the experimental flume. There was a continuous refreshment of water and feeding took place every two days. Mortality was registered and during the experimental period a supplementing of some species was necessary to keep the numbers to the required standard (see Table 1).

Table 1. Overview of the fish species used in the experiments

Group	Species	Maximal Number *	Mean length
			cm
1	*Perca fluviatilis*	4	19.8
	Esox Lucius	47	38.8
2	*Perca fluviatilis*	8	20.1
	Esox Lucius	44	38.1
3	*Carassius auratus gibelio*	25 (50)	12.4
	Gobio gobio	36 (39)	11.4
	Scardinius erythrophthalmus	53 (74)	13.4
	Leuciscus idus	43 (43)	18.0
	Perca fluviatilis	- (44)	11.1
4	*Carassius auratus gibelio*	25	12.0
	Gobio gobio	45 (44)	11.7
	Scardinius erythrophthalmus	52 (73)	13.6
	Leuciscus idus	43 (58)	17.7

* Maximal numbers after supplementing during experiments are indicated between brackets

2.2 *Experimental flume*

A de Wit fishpass prototype was built in an experimental flume (length: 56.00 m, width: 2.40 m, depth: 1.45 m). The floor was covered with a 0.15 m layer of riprap. The discharge to the flume has a maximum of 0.600 m^3/s. The waterlevel in the flume is regulated by two weirs at both upstream and downstream end. Both weirs have a fixed sill level of 0.70 m.

2.3 *Selection of parameters*

One of the goals of this study was to get insight in the impact of stream velocity and possible effects due to the length of the fishpass. As mentionned above overall waterlevel difference H_{tot} and the number of walls T are crucial factors. Hence these factors play a key role in the research.

2.4 *Parameter values*

2.4.1 *Range*

Due to the limited flume depth and the fixed sill level at the downstream end of the flume the maximal difference in water level up and downstream the fispass was restricted to ± 0.65 m. For the parameter H_{tot} two other values were chosen: 0.35 m and 0.50 m. Further several values for the parameter T were investigated. In total four different fishpasses were built with 6, 12, 18 and 24 walls respectively. Table 2 shows an overview of the different values for these parameters, indicating the corresponding velocity as calculated with formula (1) (considering $C_V = 1$).

All other parameters were kept constant during the research. Among these are distance between walls (1.0 m), fishpass width (1.80 m), orifice height (0.50 m) and orifice width (0.20 m).

Table 2. Overview of the values for H_{tot} and T and their corresponding velocity (m/s). The order in which experiments were done is indicated between brackets

Waterlevel difference H_{tot}	Number of walls T			
m	6	12	18	24
0.35	1.07 (9)	0.76 (7)	0.62 (2)	0.53 (4)
0.50	1.28 (11)	0.90 (8)	0.74 (5)	-
0.65	1.46 (10)	1.03 (6)	0.84 (1)	0.63 (3)

2.4.2 *Motivation, restrictions and consequences*

Based on literature and own experience stream velocities ranging from 0.5 to 1.0 m/s were expected to be acceptable for upstream migration. In addition two experiments with higher velocities were investigated to meet more extreme situations on the field.

At the beginning focus was set on those combinations which created a velocity of about 0.75 m/s. Comparison of these combinations, which are roughly situated on the diagonal in Table 2, can tell something about the possible impact of the number of walls (as H_{tot} remains constant). The effect of velocity was investigated by comparison of the combinations situated in either the same row or same column in Table 2.

Ideally the experiments should be done in a random order. In practice this seemed rather impossible, because changing the number of walls and thus rebuilding the fishpass took quite some effort and time. Therefore experiments with the same number of walls were grouped together (see Table 2). This implies that possible effects of time could hide the impact of the parameters under consideration. First experiments with lower stream velocities were done, while higher stream velocities came at the end of the research. Hence lower success in clearing the fishpass at higher velocities could also be caused by lower vitality. Also mortality caused a decrease of the number of fish in a group as time went on. As conserving the precision of the experiments and the overall condition/vitality of the groups was preferred to the conservation of the experimental unity of the groups, supplementing of the groups with fresh fish was done during experiments (see Table 1).

2.5 *Statistical analysis*

The success of a fish in clearing a fishpass can be considered as a variable with a binomial distribution. More precisely the success was calculated as the proportion of fish that arived at the upstream end of the fishpass to the total number of fish that started at the downstream end.

By using a statistical model it is possible to split up the results in a deterministic and a stochastic part. The most apted statistical model to use for a binomial variable is a logistic regression model. It discribes the relation between the mean chance to success (output variable) and the parameters in the experiment (input variables) namely stream velocity and number of walls.

3 RESULTS

Figures 1, 2 and 3 summarize all experimental results. For each species the original measurements (success) are shown as a function of the (calculated) velocity. The best fitting logistic regression curve together with a 95 % confidence interval is presented.

3.1 *Discussion of stochastic part*

For almost all species we see larger fluctiations than would be expected from a binomial distribution. This overdispersion could be due to the fact that the control over the circumstances under which the experiments took were done not good enough. Experiments with living material are known to be rather sensitive to minor disturbances.

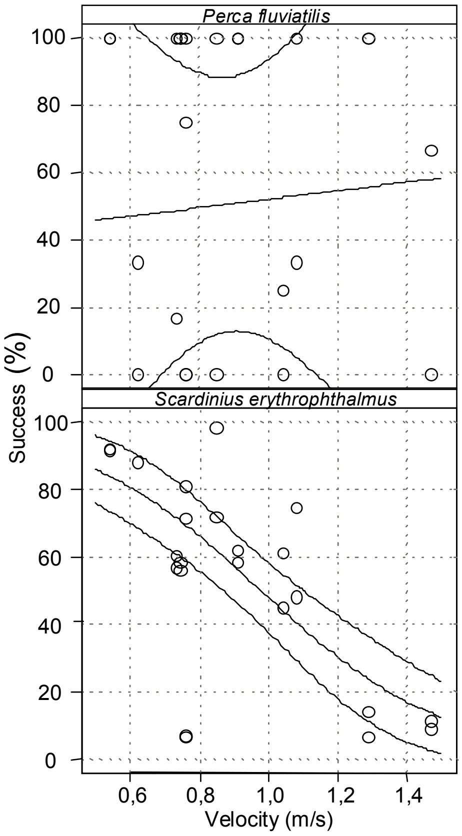

Figure 1. Results for *P. fluviatilis* and *S. erythrophthalmus*

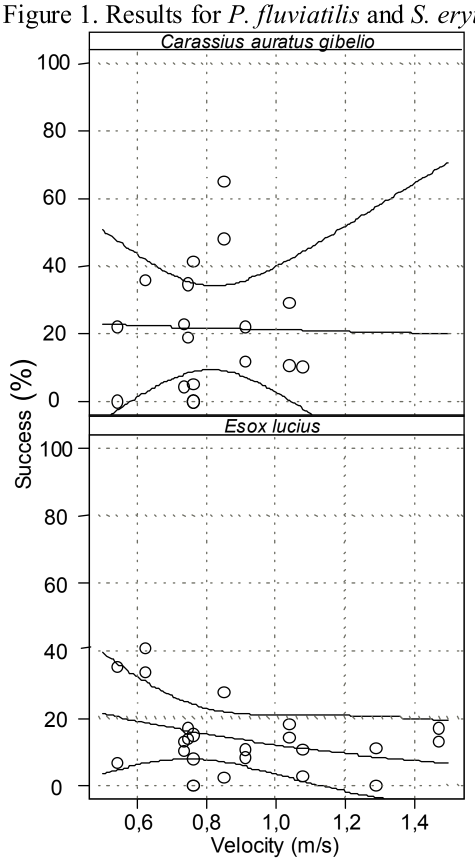

Figure 2. Results for *C.auratus gibelio* and *E. lucius*

The inconsistency in the results for *P. fluviatilis* can be explained by the very low number of individuals. The wide confidance intervals do not allow conclusions. The results for *C. auratus gibelio* and

G. gobio have also relative wide confidance intervals, especially when velocity gets above 1 m/s. This is because the experiments for this higher velocities had been cancelled due to a too high mortality. In this region the estimated (mean) curve is an extrapolation. For the three other species the width of the confidance intervals is rather normal.

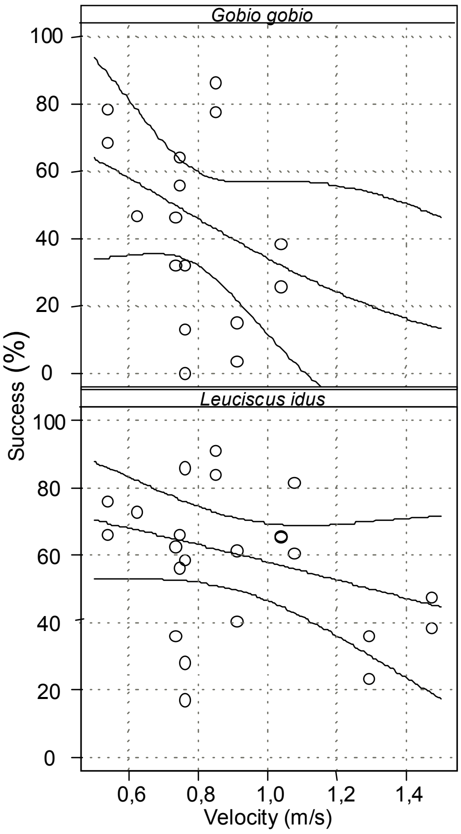

Figure 3. Results for *G. gobio* and L. *idus*

3.2 *Discussion of deterministic part*

The mean success - considered over the full range of velocities - differs very strong depending on the species. For *E. lucius* and *C. auratus gibelio* the mean success is rather low (10-20 %), while *S. erythrophthalmus*, *G. gobio* and *L. idus* have higher values for mean success. *P. fluviatilus* is not considered because of the low numbers.

Roughly spoken there is a strong and significant negative impact of the velocity. This negative relation is most pronounced for *S. erythrophthalmus* (success varying from 90 % at low velocities to < 20 % at high velocities). The negative impact can also be seen for *L. idus* (70 to 50 %), *E. lucius* (20 to 10 %) and *G. gobio* (60 to< 20 %; extrapolated!).

In these models abstraction is made of the number of walls, because this parameter seemed to have no effect within the range of values under consideration.

Detailed analysis per species (not discussed in this paper) confirmed the decreasing success with increasing velocities. However the results could also be explained with a (negative) stepfunction with a possible threshold value at a velocity of about 1.0 m/s. Once this velocity is exceeded, the success drops. Whatever the model that is chosen, the value of 1.0 m/s seems to be a significant value.

3.3 *Conclusions*

Each species was able to clear the fishpass successfully. At least a few individuals arrived at the upstream end. Velocity had a dominant and negative impact on the success. It is important to mention that low success rates (e.g. for *E. lucius*) can be due to a complete abscence of any force to migrate upstream. This can be expected to be typical for experiments done in a totally unnatural environment.

4 DESIGN RULES

Figure 4 presents graphical design rules based on the results of this research. The lower left area is covered by experimental research, while the rest of the area is based on extrapolations of these results. Designs coming from this zone in the graph should therefore always be coupled to a monitoring campaign.

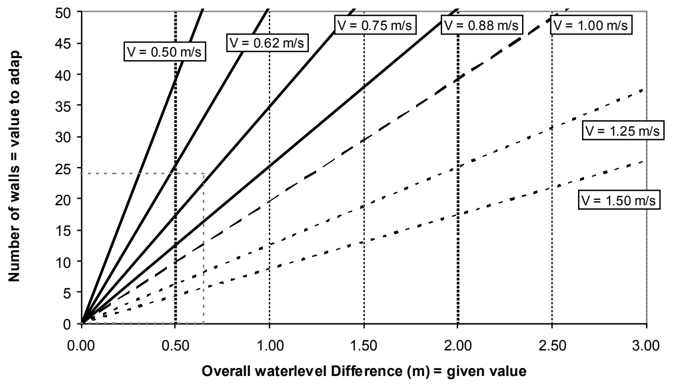

Figure 4. Graphical presentation of design rules

5 CONCLUSIONS

Taking into account several boundary conditions:

- stream velocities range from 0.50 to 1.50 m/s, with focus on velocities up to 1 m/s;
- overall waterlevel difference is limited to 0.65 m;
- the fishpass has a maximum of 24 walls;
- 6 species are included, but due to mortality results do not cover the full velocity range for each one;
- the results show strong fluctuations relative the the deducted statistical model;

the research shows a significant negative impact of stream velicities on the clearing success for a de Wit fishpass. The success remains high for velocities up to 1.0 m/s. Higher velocities reduce success strongly. This conclusions apply for *S. erythrophthalmus*, *L. idus*, *E. lucius* and *G. gobio*. Extrapolation of these results are preferably coupled to a monitoring program.