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 successful clearing of the fishpass for several lowland fish species. Final goal was to present design rules for constructing successfully 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 hydrographic 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 constructions 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 developed 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 The vertical slots have been replaced by rectangular orifices close to the bottom.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 $H_{\text{tot}}$ (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:

\begin{align*}
V &= C_V \times \sqrt{\frac{2 \times g \times H_{\text{tot}}}{T}} \quad (1) \\
Q &= C_D \times V \times A \quad (2)
\end{align*}

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 $H_{\text{tot}}$ 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 $T_{\text{optimal}}$ causing no problems for fish migration and $T_{\text{critical}}$ 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 consideration, 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 ichthyofauna 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>
<thead>
<tr>
<th>Group</th>
<th>Species</th>
<th>Maximal Number</th>
<th>Mean length cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Perca fluviatilis</td>
<td>4</td>
<td>19.8</td>
</tr>
<tr>
<td></td>
<td>Esox Lucius</td>
<td>47</td>
<td>38.8</td>
</tr>
<tr>
<td>2</td>
<td>Perca fluviatilis</td>
<td>8</td>
<td>20.1</td>
</tr>
<tr>
<td></td>
<td>Esox Lucius</td>
<td>44</td>
<td>38.1</td>
</tr>
<tr>
<td>3</td>
<td>Carassius auratus gibelio</td>
<td>25 (50)</td>
<td>12.4</td>
</tr>
<tr>
<td></td>
<td>Gobio gobio</td>
<td>36 (39)</td>
<td>11.4</td>
</tr>
<tr>
<td></td>
<td>Scardinius erythrophthalmus</td>
<td>53 (74)</td>
<td>13.4</td>
</tr>
<tr>
<td></td>
<td>Leuciscus idus</td>
<td>43 (43)</td>
<td>18.0</td>
</tr>
<tr>
<td></td>
<td>Perca fluviatilis</td>
<td>- (44)</td>
<td>11.1</td>
</tr>
<tr>
<td>4</td>
<td>Carassius auratus gibelio</td>
<td>25</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>Gobio gobio</td>
<td>45 (44)</td>
<td>11.7</td>
</tr>
<tr>
<td></td>
<td>Scardinius erythrophthalmus</td>
<td>52 (73)</td>
<td>13.6</td>
</tr>
<tr>
<td></td>
<td>Leuciscus idus</td>
<td>43 (58)</td>
<td>17.7</td>
</tr>
</tbody>
</table>

* 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 m³/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 mentioned 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 fishpass was restricted to \( \pm 0.65 \) 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>
<thead>
<tr>
<th>Waterlevel difference ( H_{tot} ) m</th>
<th>6</th>
<th>12</th>
<th>18</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.35</td>
<td>1.07 (9)</td>
<td>0.76 (7)</td>
<td>0.62 (2)</td>
<td>0.53 (4)</td>
</tr>
<tr>
<td>0.50</td>
<td>1.28 (11)</td>
<td>0.90 (8)</td>
<td>0.74 (5)</td>
<td>-</td>
</tr>
<tr>
<td>0.65</td>
<td>1.46 (10)</td>
<td>1.03 (6)</td>
<td>0.84 (1)</td>
<td>0.63 (3)</td>
</tr>
</tbody>
</table>

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 arrived 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 describes 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 fluctuations 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.
**G. gobio** have also relative wide confidence 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 confidence intervals is rather normal.

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. fluviatilis** 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**, **G. gobio** and **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 absence 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.

### 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 velocities 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.