Session B5 - Modeling brook trout (Salvelinus fontinalis) passage success through road culverts: from theory to reality

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Modelling brook trout passage success through road culverts: from theory to reality

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Introduction

- Culverts often create velocity barriers that may impede upstream fish passage and fragment riverscape habitat.

- Predictive approaches of fish passage success have been developed using fish swimming capacity data generally obtained in laboratory.

- Few studies have attempted to validate these approaches in natural culverts.
Objective

Determine the correspondence between

- **Observations** of brook trout passage success/failure through natural culverts using PIT telemetry

  and

- **Predictions** of fish passage success/failure for the same conditions using the ‘maximum distance of ascent’ approach of Castro-Santos (2005)
Study sites

Nine culverts of southern Québec:

- 6 corrugated metal circular culverts
- 2 concrete circular smooth culverts
- 1 concrete box smooth culvert
- Slopes from 0.3 to 4.5%
- Length from 9 to 45 m.
Data collection

Semi-experimental approach

- Fish passage trials conducted at various culverts, discharges and water temperatures
- For each trial, a group of 24 PIT-tagged brook trout is released for 48h in a cage fixed at culvert outlet
- 3 size groups ($F_1$)
  - Small: 90 à 119 mm
  - Medium: 120-149 mm
  - Large: 150-230 mm

(E. Goerig, 2009)
Data collection

Fish passage attempts, progression and success monitored with four PIT antennas inside culvert

Modified from Cahoon et al. (2004)

23 mm half-duplex PIT-tags (Texas Instrument)
Culvert and hydraulic measurements

Culvert
- Type, diameter, length, slope

Hydraulics at 2 m spaced transects
- 3 measures of flow velocity, depth
- Before and after trial

Water temperature and water level
- Continuously during trial

(E. Goerig 2009)
PIT-tagged fish swimming data

- Groundspeed ($U_g$)
  \[ U_g = \frac{D}{T(A2 - A1)}(A2 - A1) \]
  Computed only for fish that reached at least antenna 2
  The attempt with the farthest ascent distance is used

- Swim speed ($U_s$)
  \[ U_s = U_g + U_f \]
  where $U_f$ is mean flow velocity
Summary of field data

- 40 trials
  - 27 in rough culvert
  - 13 in smooth culvert
- 958 brook trout of 90-230 mm

Flow velocity range:
- Corrugated metal: 0,5 à 1,6 m s\(^{-1}\)
- Smooth concrete: 0,3 à 2 m s\(^{-1}\)

Water temperature range:
- Corrugated metal: 3 à 16 °C
- Smooth concrete: 9 à 19 °C
Predictive approach

- Laboratory data relating swim speed to time to fatigue for brook trout in prolonged swim mode (Peake, 1997)

- Varies with fish length and water temperature:
  - Range of length: 63-259 mm
  - Range of temperature: 14-20°C

\[
\ln = a + bU_s
\]
Distance of ascent (Dg)

Castro-Santos (2005)

\[ D_g = \left[ (U_f - \frac{1}{b}) - U_f \right] \times e^{a + b(U_f - \frac{1}{b})} \]

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\[ D_g = \left[ (U_f - \frac{1}{b}) - U_f \right] \times e^{a + b(U_f - \frac{1}{b})} \]

\[ D_g = \text{groundspeed} \times \text{fatigue time} \]

Optimal swim speed \( U_{\text{opt}} \):
\[ U_{\text{opt}} = U_{\text{flow}} - \frac{1}{b} \]

Assume optimal swim speed:
\[ D_{\text{max}} = \left( U_{\text{opt}} - U_{\text{flow}} \right) \times \exp \left( a + b U_{\text{opt}} \right) \]

\[ D_{\text{max}} = \left( U_{\text{opt}} - U_{\text{flow}} \right) \times \exp \left( a + b U_{\text{opt}} \right) \]

Compare \( D_{\text{max}} \) to culvert length to predict success/failure
## Observed vs predicted

### Passage success

<table>
<thead>
<tr>
<th></th>
<th>Passage Success (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
</tr>
<tr>
<td>Observed</td>
<td>45</td>
</tr>
<tr>
<td>Predicted</td>
<td>28</td>
</tr>
</tbody>
</table>

N= 958 fish. 493 (51%) did at least one attempt

### Predictive model underestimates passage success

- How good is the model at predicting the possible outcomes of an attempt?
- In what situations does it perform better or worst?
## Observed vs predicted

### Confusion matrix

#### Corrugated metal culverts

<table>
<thead>
<tr>
<th>Prédictions</th>
<th>Success</th>
<th>Failure</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success</td>
<td>33</td>
<td>35</td>
<td>68</td>
</tr>
<tr>
<td>Failure</td>
<td>88</td>
<td>89</td>
<td>177</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>121</td>
<td>124</td>
<td>245</td>
</tr>
</tbody>
</table>

Correct classification rate (CCR): 50%

Misclassifications:
- **Underpredict**: 72%
- **Overpredict**: 28%

#### Smooth concrete culverts

<table>
<thead>
<tr>
<th>Prédictions</th>
<th>Success</th>
<th>Failure</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success</td>
<td>52</td>
<td>18</td>
<td>70</td>
</tr>
<tr>
<td>Failure</td>
<td>51</td>
<td>133</td>
<td>184</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>103</td>
<td>151</td>
<td>254</td>
</tr>
</tbody>
</table>

Correct classification rate (CCR): 73%

Misclassifications:
- **Underpredict**: 73%
- **Overpredict**: 27%
Why are predictions better in smooth than rough culverts?

- Conditions maybe more similar to lab conditions where fish swimming capacity data were obtained
- Different fish behaviour?
- Fish may use corrugations?
- Sequence of burst swim / rest period
- Fish may have access to more lower velocity zones
- Smaller fish maybe better at this
# Effect of fish size and flow velocity

## Fish size

<table>
<thead>
<tr>
<th>Fish length (FL = mm)</th>
<th>n</th>
<th>CCR (%)</th>
<th>TP (%)</th>
<th>TN (%)</th>
<th>FP (%) overpredict</th>
<th>FN (%) underpredict</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small (90-119)</td>
<td>176</td>
<td>63</td>
<td>87</td>
<td>13</td>
<td>5</td>
<td>95</td>
</tr>
<tr>
<td>Medium (120-149)</td>
<td>197</td>
<td>59</td>
<td>73</td>
<td>27</td>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td>Large (150 +)</td>
<td>126</td>
<td>63</td>
<td>49</td>
<td>51</td>
<td>57</td>
<td>43</td>
</tr>
</tbody>
</table>

## Flow velocity

<table>
<thead>
<tr>
<th>Flow velocity (m s⁻¹)</th>
<th>n</th>
<th>CCR (%)</th>
<th>TP (%)</th>
<th>TN (%)</th>
<th>FP (%) overpredict</th>
<th>FN (%) underpredict</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (0-0.7)</td>
<td>150</td>
<td>28</td>
<td>76</td>
<td>24</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Intermediate (0.7-1.3)</td>
<td>256</td>
<td>57</td>
<td>6</td>
<td>94</td>
<td>6</td>
<td>94</td>
</tr>
<tr>
<td>High (1.3-2)</td>
<td>92</td>
<td>82</td>
<td>0</td>
<td>100</td>
<td>6</td>
<td>94</td>
</tr>
</tbody>
</table>
Effect of water temperature

<table>
<thead>
<tr>
<th>Water temperature (°C)</th>
<th>n</th>
<th>CCR (%)</th>
<th>TP (%)</th>
<th>TN (%)</th>
<th>FP (%) overpredict</th>
<th>FN (%) underpredict</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (5-10)</td>
<td>61</td>
<td>57</td>
<td>29</td>
<td>71</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Intermediate (10-15)</td>
<td>206</td>
<td>65</td>
<td>20</td>
<td>80</td>
<td>14</td>
<td>86</td>
</tr>
<tr>
<td>High (15-20)</td>
<td>232</td>
<td>60</td>
<td>31</td>
<td>69</td>
<td>17</td>
<td>83</td>
</tr>
</tbody>
</table>

- Misclassifications of the model are mainly underpredictions of passage success
- Overpredictions at low temperature, low velocity and for large fish.
- Interaction between variables?
Deviation from optimal groundspeed

- Some fish swim close to the predicted optimum, but others deviate.
- The ones that deviate most were correctly predicted by the approach as true failures.
- The underpredicted cases had a groundspeed $\Rightarrow$ of the optimum.

![Graph showing deviation from predicted groundspeed](Image)

- Underpredictions
- Overpredictions
Deviation from maximal distance of ascent

- The approach underpredicts Dmax for false negatives
- Dmax overpredicted for false positives
- Dmax overpredicted even for true negatives

![Deviation to predicted maximal distance of ascent (m)](image)

Correct classifications
Misclassifications

Underpredictions
Overpredictions
Is optimal groundspeed efficient to predict passage capacity?

- Better at predicting true failures than success which is often underestimated.

- Mean flow velocity may not be the appropriate input:
  - What is the real nose velocity experienced by the fish?
  - What is the appropriate correction factor to use?
  - How does it vary with fish size and culvert type?
  - Need more knowledge of fish swimming behaviour in different types of culverts and flow conditions.
What’s to come?

• Further exploration of the confusion matrix.

• Simulations with FishXing;

• Analysis of multiples attempts and passages for each fish;

• Analysis of groundspeed values during the ascent in relation to flow velocity distribution in cross section
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