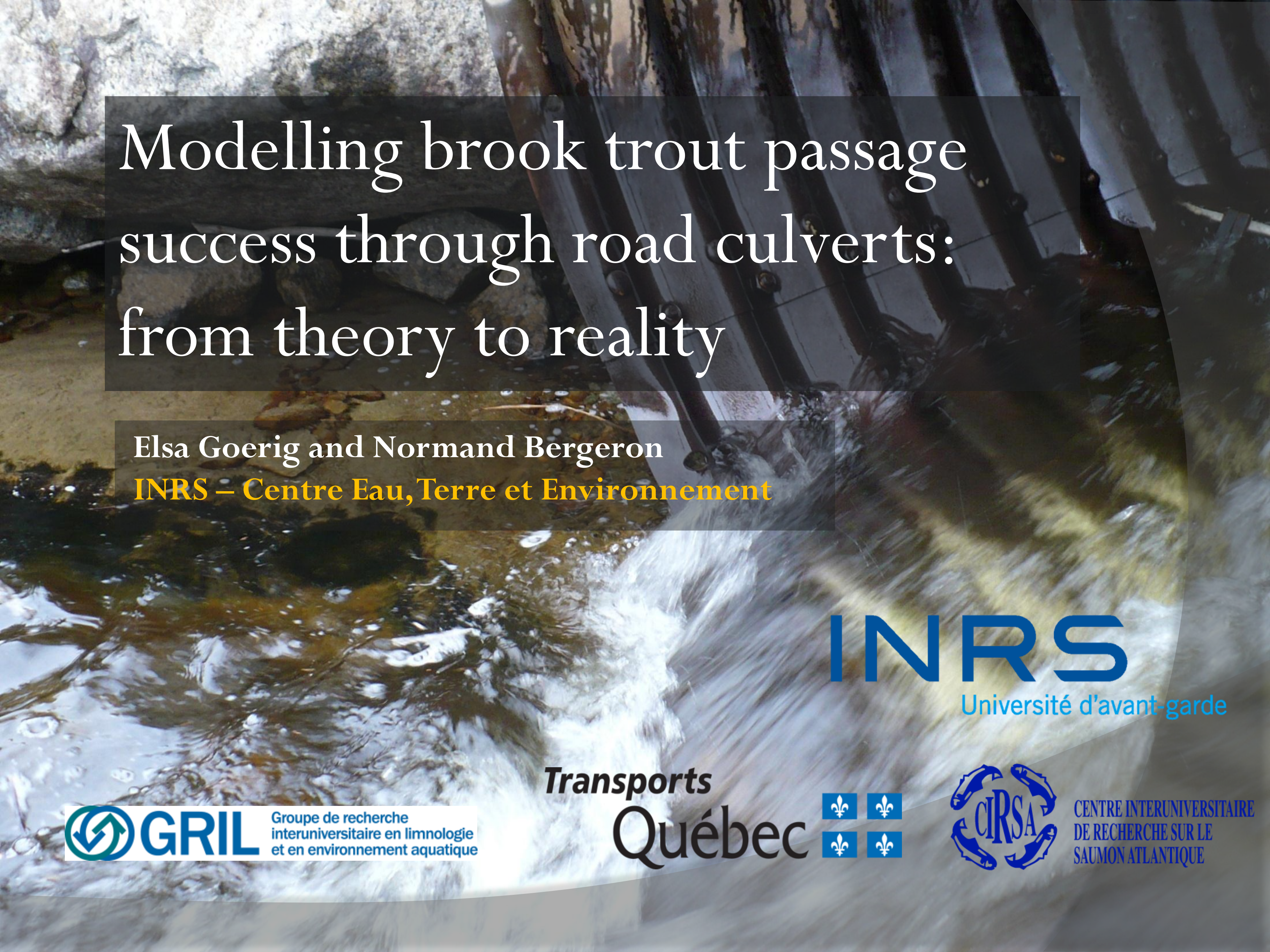
Jun 6th, 2:10 PM - 2:30 PM

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

Elsa Goerig
Institut National de la Recherche Scientifique (INRS), Centre Eau, Terre et Environnement PhD program in earth sciences,
elsa.goerig@ete.inrs.ca

Goerig, Elsa, "Session B5 - Modeling brook trout (Salvelinus fontinalis) passage success through road culverts: from theory to reality" (2012). *International Conference on Engineering and Ecohydrology for Fish Passage*. 25.
https://scholarworks.umass.edu/fishpassage_conference/2012/June6/25



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

Elsa Goerig and Normand Bergeron
INRS – Centre Eau, Terre et Environnement

INRS
Université d'avant-garde

GRIL
Groupe de recherche interuniversitaire en limnologie et en environnement aquatique

Transports Québec

CIRSA
CENTRE INTERUNIVERSITAIRE DE RECHERCHE SUR LE SAUMON ATLANTIQUE

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

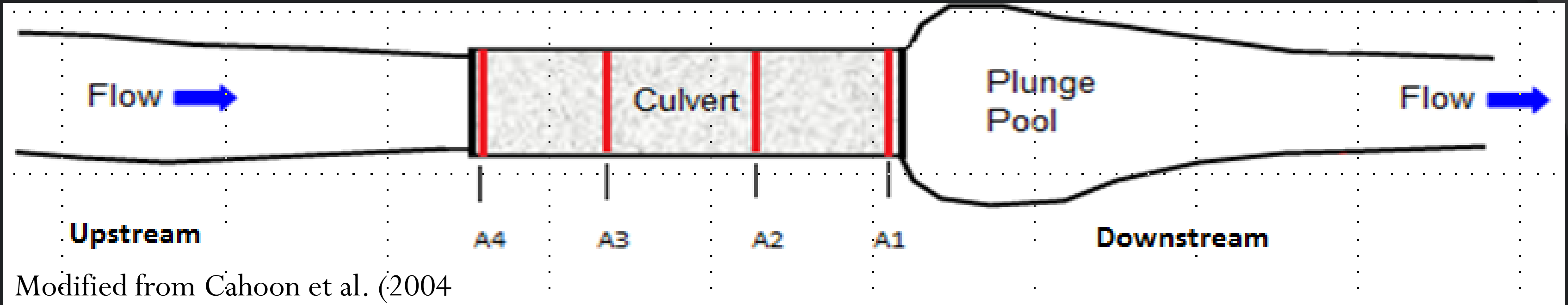
Semi-experimental approach

- 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_l)
  - 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 (*Ug*)

$$Ug = \frac{D}{T(A2 - A1)}(A2 - A1)$$

> Computed only for fish that reached at least antenna 2
>
> The attempt with the farthest ascent distance is used

- Swim speed (Us)

$$Us = Ug + Uf$$

where *Uf* is mean flow velocity

Summary of field data

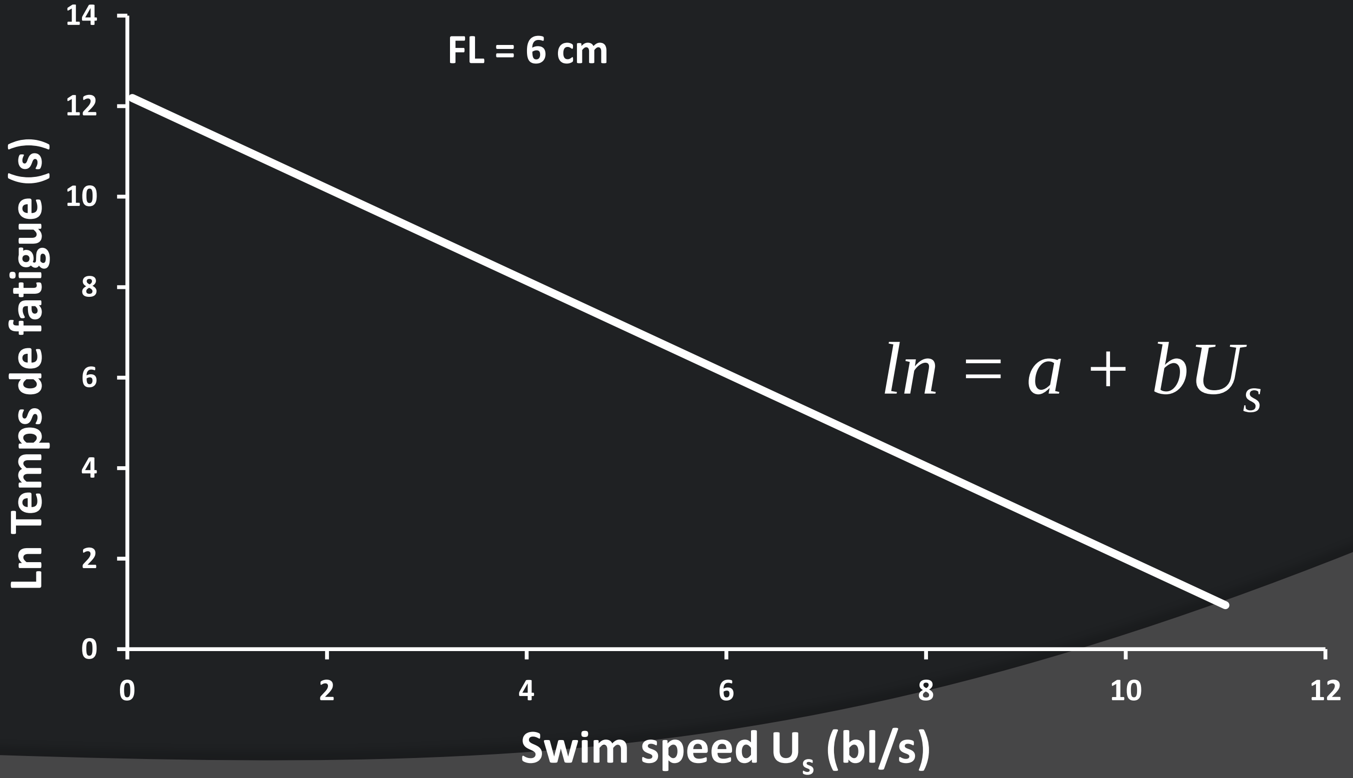
- 40 trials
  - 27 in rough culvert
  - 13 in smooth culvert
- 958 brook trout of 90-230 mm

	Corrugated metal	**Smooth concrete**
Flow velocity range:	0,5 à 1,6 m s^{-1}	0,3 à 2 m s^{-1}
Water temperature range:	3 à 16 °C	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 temperatur:

Range of length: 63-259 mm
Range of temperature: 14-20°C



$$ln = a + bU_s$$

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

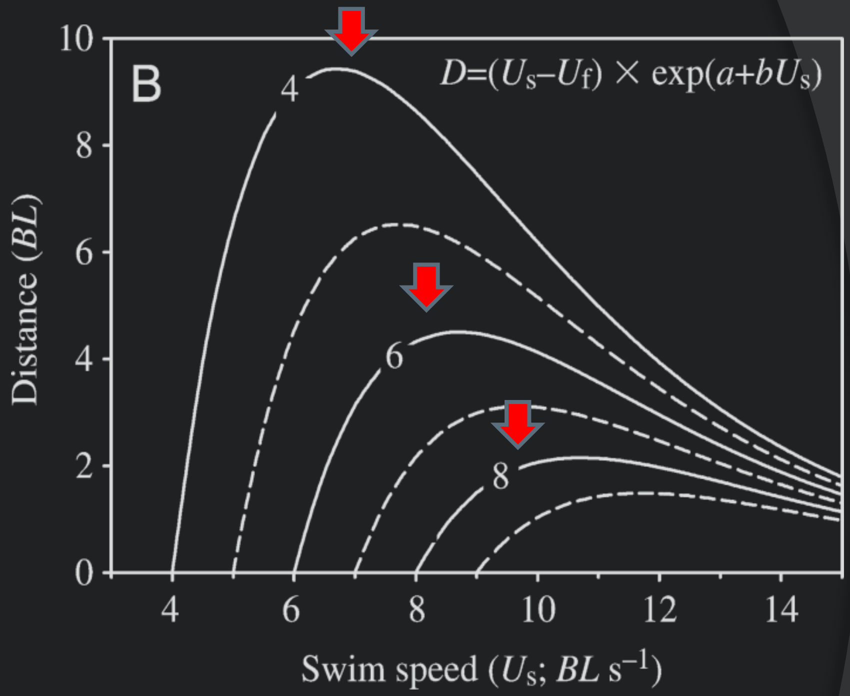
$$D_g = \left[\left(U_f - \tfrac{1}{b}\right) - U_f\right] \times e^{a+b\left(U_f - \tfrac{1}{b}\right)}$$

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

Distance of ascent (Dg)

Castro-Santos (2005)

D_g = groundspeed x fatigue time



Optimal swim speed U_{opt}:

$$U_{opt} = U_{flow} - 1/b$$

Assume optimal swim speed:

$$D_{max} = (U_{opt} - U_{flow}) \text{ x } \exp(a + b\, U_{opt})$$

➡ Compare D_{max} to culvert length to predict success/failure

Castro-Santos T (2005) J Exp. Biol. 208: 421-432.

Observed *vs* predicted

Passage success

	Passage Success (%)		
	All	**Rough culvert**	**Smooth culvert**
Observed	45	50	41
Predicted	28	28	28

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 ?

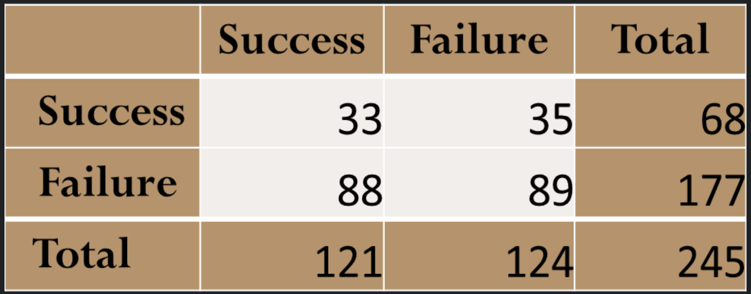
Observed *vs* predicted

Confusion matrix

Corrugated metal culverts

Observations

Prédictions



	Success	Failure	Total
Success	33	35	68
Failure	88	89	177
Total	121	124	245

Correct classification rate (CCR): 50 %

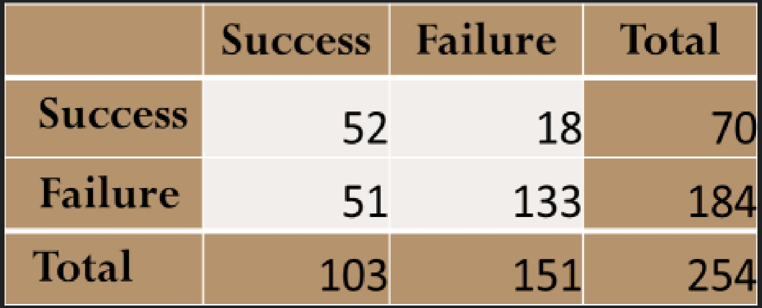
Misclassifications

Underpredict : 72%
Overpredict : 28%

Smooth concrete culverts

Observations

Prédictions



	Success	Failure	Total
Success	52	18	70
Failure	51	133	184
Total	103	151	254

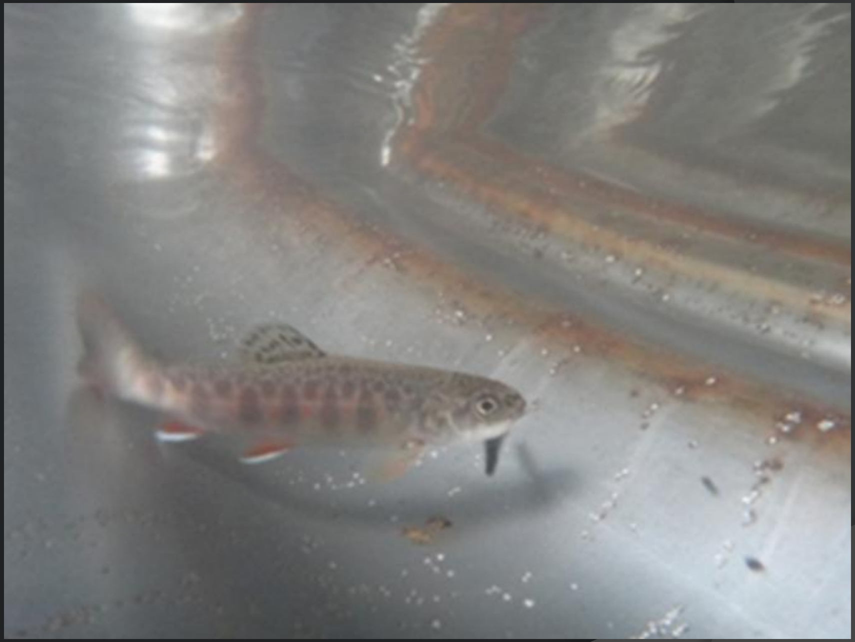
Correct classification rate (CCR) : 73 %

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



Elsa Goerig (INRS) 2011

Effect of fish size and flow velocity

Fish size

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

Flow velocity

Flow velocity (m s-^{1})	n	CCR (%)	TP (%)	TN (%)	FP (%) overpredict	FN (%) underpredict
Low (0-0.7)	150	28	76	24	75	25
Intermediate (0.7-1.3)	256	57	6	94	6	94
High (1.3-2)	92	82	0	100	6	94

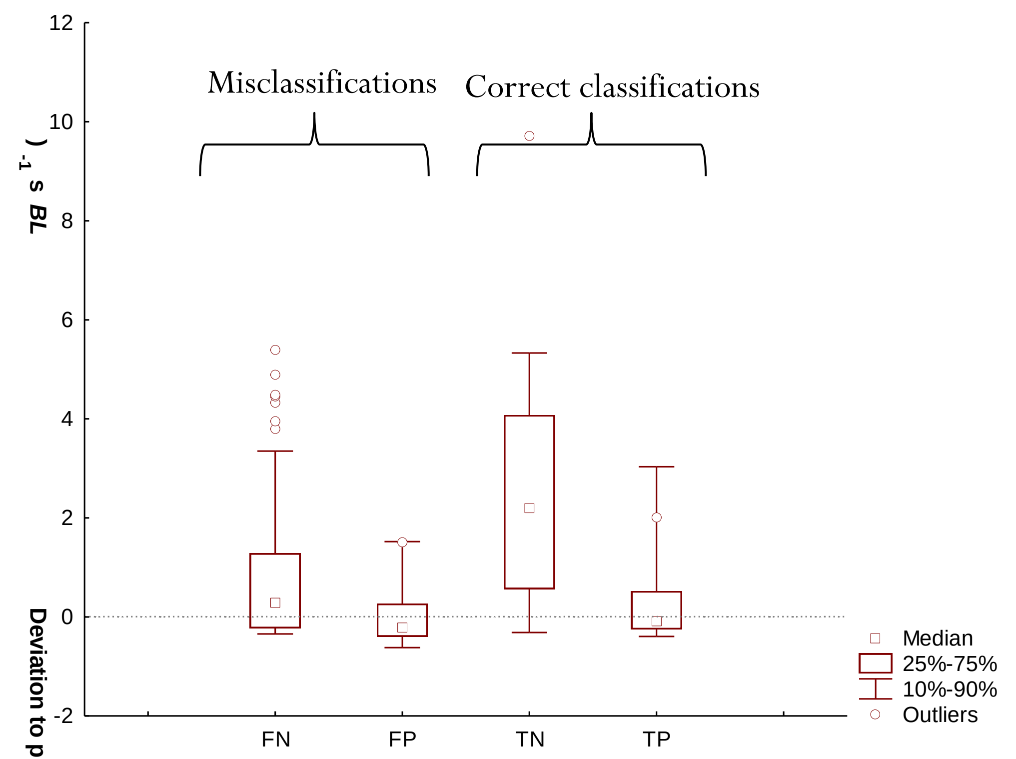
Effect of water temperature

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

- 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 => of the optimum

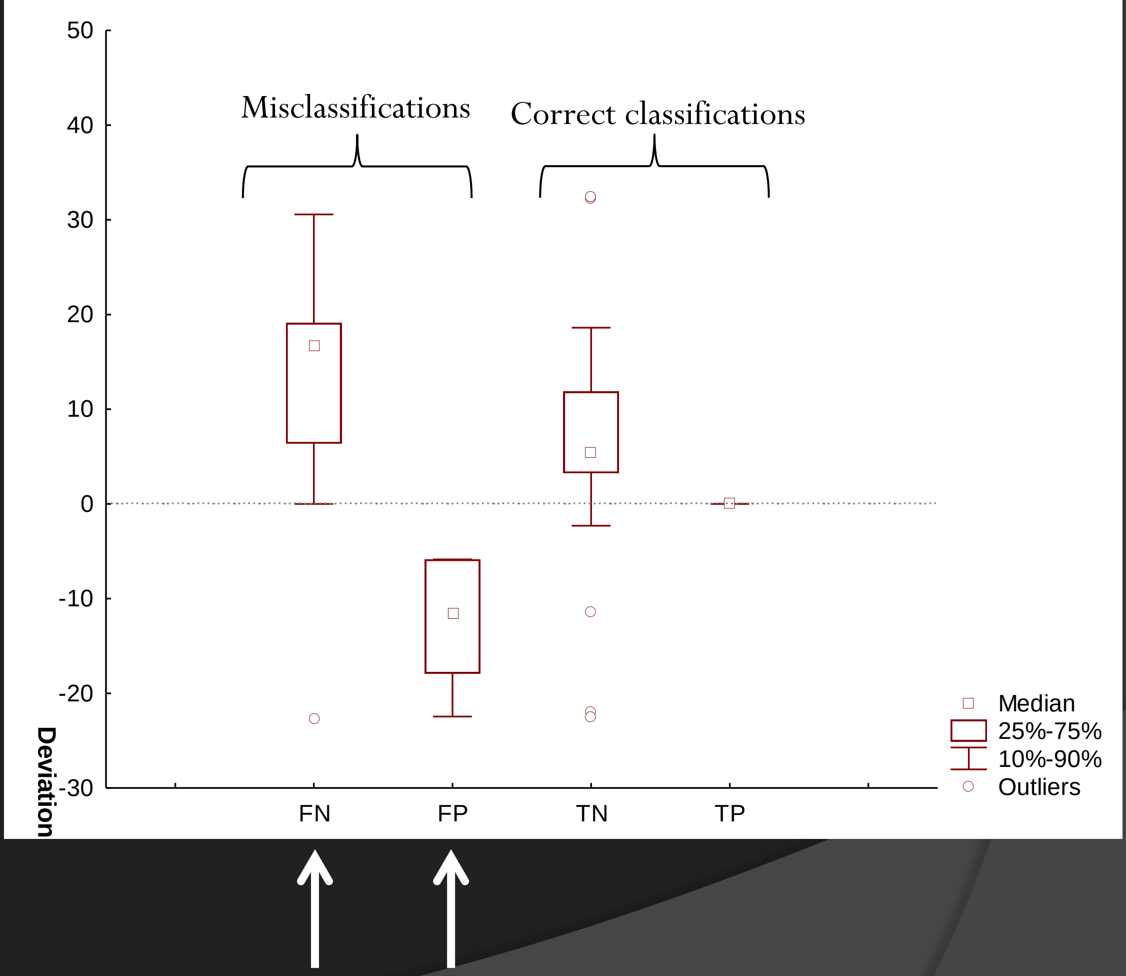


Underpredictions ↑ FN

Overpredictions ↑ FP

Deviation from maximal distance of ascent

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



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 doest 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

Smooth concrete culvert
Elsa Goerig (INRS) 2011

Acknowledgements

Normand Bergeron, research supervisor

Workmates :

Jean-Baptiste Torterotot,
Steve Dugdale,
Marc-André Pouliot
Francis Bérubé
André Boivin
Carole-Anne Gillis,
Laurie Beaupré

The research assistants in the field:

Maxim Fortin,
Hugo Bouchard
Christine Larouche
Pascal Marcotte
Flavien Pichon
Joelle Bédard
Clément Clerc.

Financial partners:

Transports Québec

Fonds de recherche Nature et technologies Québec

NSERC CRSNG