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Session B7- Cyprinid swimming behaviour response to turbulent flow in pool-type fishways

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Cyprinid swimming behaviour response to turbulent flow in pool-type fishways

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Background

- Turbulence affects swimming behaviour, performance and stability, bioenergetic costs, habitat selection and group density for fish. Associated turbulent descriptors include: turbulent kinetic energy (TKE), Reynolds shear stress (τ), turbulence intensity (TI), strain, eddy size, orientation and vorticity.

Pavlov, Lupandin and Skorobogatov 2000;

Liao, Beal, Lauder and Triantafyllou 2003;

Enders, Boisclair and Roy 2003;

Lupandin 2005;

Smith, Brannon, Shafii and Odeh 2006;

Cotel, Webb and Tritico 2006;

Liao 2007;

Pavlov, Mikheev, Lupandin and Skorobogatov 2008;

Tritico and Cotel 2010;

Webb and Cotel 2010;

Pool & Weir Fishways: Silva, Santos, Ferreira, Pinheiro and Katopodis 2010 & 2011

Objectives

- To extend the study of turbulence effects (Reynolds shear stress, TKE, TI) in some Pool & Orifice fishway configurations reported by Silva et al. 2010 & 2011.
- To examine effects of eddy size on the swimming behaviour of the rheophilic potamodromous Iberian barbel (*Luciobarbus bocagei*) in three different configurations of a Pool & Orifice fishway.

Laboratory ecohydraulic flume



- Flume: 10m x 1m x 1.20m;
- 6 pools: 1.90m x 1m x 1.20m;
- Upstream tank : 1.5 m x 1.0 m x 1.2m;
- Downstream tank (acclimation chamber):
4m x 4m x 3m

Hydraulic measurements with 3D ADV

- small adults (N=70; $15 \leq TL < 25$ cm)
- large adults (N=70; $25 < TL \leq 35$ cm)



National Laboratory for
Civil Engineering, Lisbon

Experimental setup

1. Offset orifices

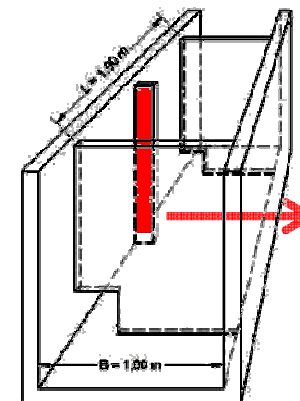
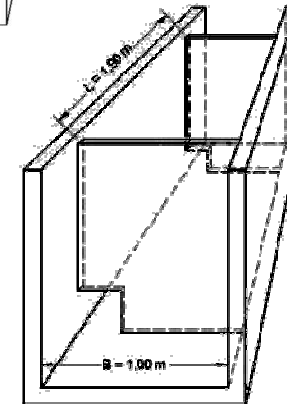
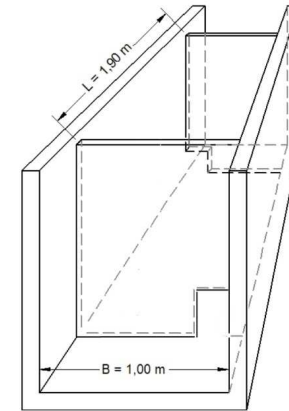
- E1: $38.5 \text{ l.s}^{-1} + 0.18 \times 0.18 \text{ m} - 37.0 \text{ W. m}^{-3}$
- E2: $47.5 \text{ l.s}^{-1} + 0.20 \times 0.20 \text{ m} - 47.2 \text{ W. m}^{-3}$
- E3: $62.7 \text{ l.s}^{-1} + 0.23 \times 0.23 \text{ m} - 63.1 \text{ W. m}^{-3}$

2. Straight orifices

- E4: $50.0 \text{ l.s}^{-1} + 0.18 \times 0.18 \text{ m} - 48.5 \text{ W. m}^{-3}$
- E5: $71.8 \text{ l.s}^{-1} + 0.20 \times 0.20 \text{ m} - 69.0 \text{ W. m}^{-3}$

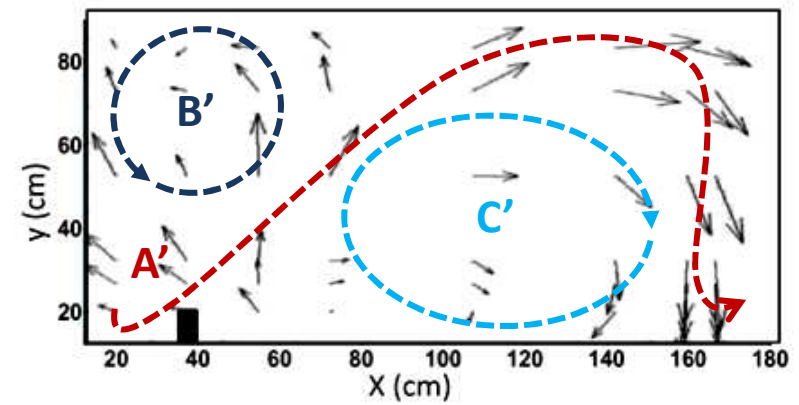
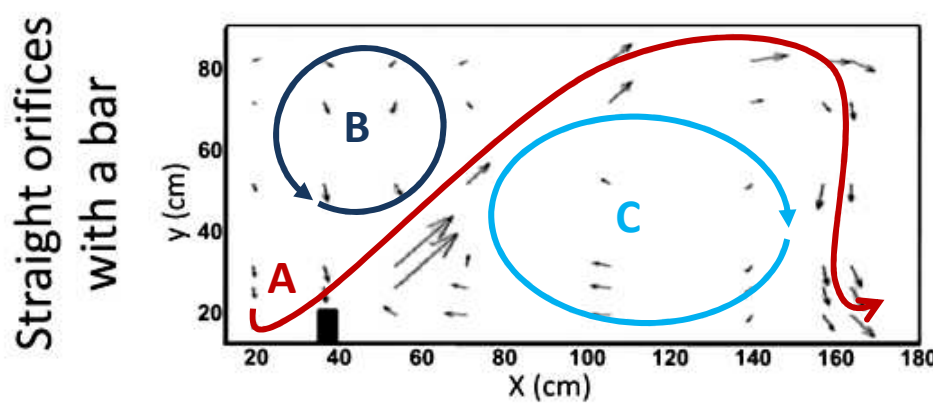
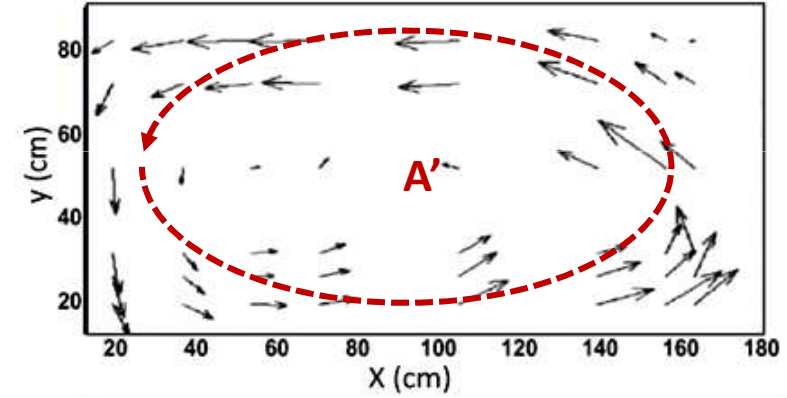
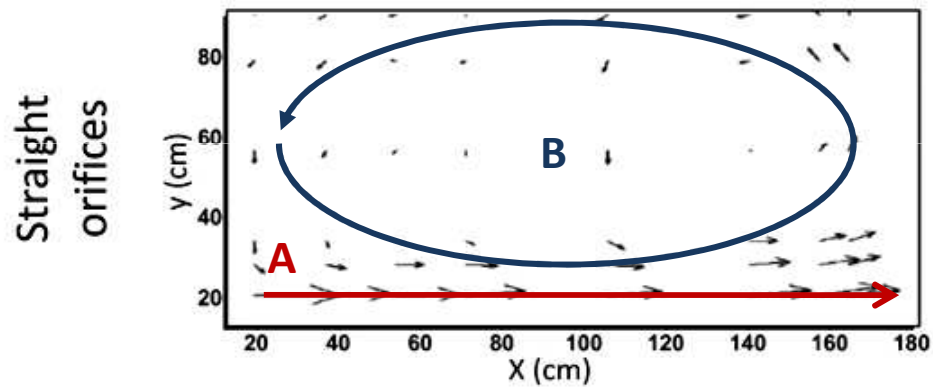
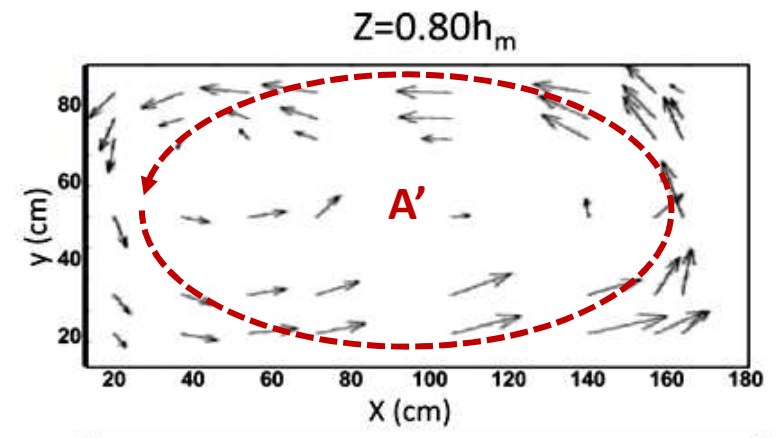
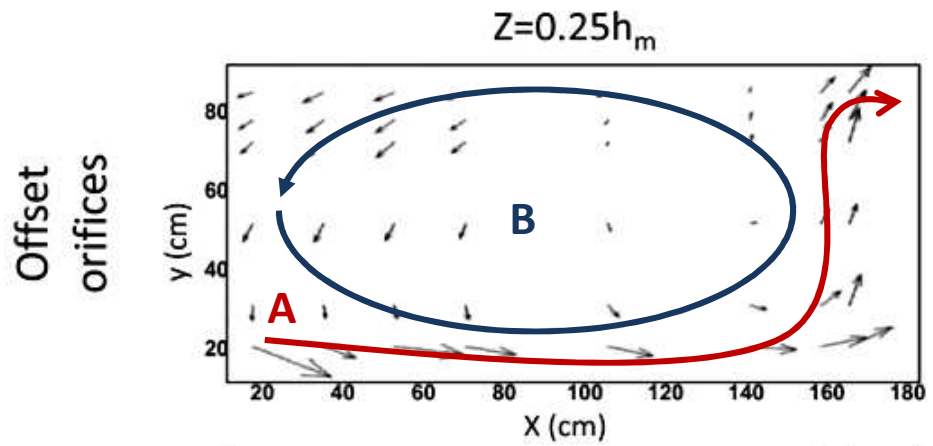
3. Straight orifices with a bar

- E6: $38.5 \text{ l.s}^{-1} + 0.18 \times 0.18 \text{ m} - 37.0 \text{ W. m}^{-3}$
- E7: $62.7 \text{ l.s}^{-1} + 0.23 \times 0.23 \text{ m} - 63.1 \text{ W. m}^{-3}$



$0.5b_o; 0.2L$

Flow topology and velocity (plan views)



Turbulent flow kinematics

- Turbulent kinetic energy (TKE)

$$\text{TKE} = \frac{1}{2} \left(u'_{\text{rms}}{}^2 + v'_{\text{rms}}{}^2 + w'_{\text{rms}}{}^2 \right)$$

- Reynolds shear stress (τ_{xy}) $= \rho \overline{u'v'}$

- Turbulence intensity (TI) $\text{TI} = \frac{\text{TKE}}{U^2}$

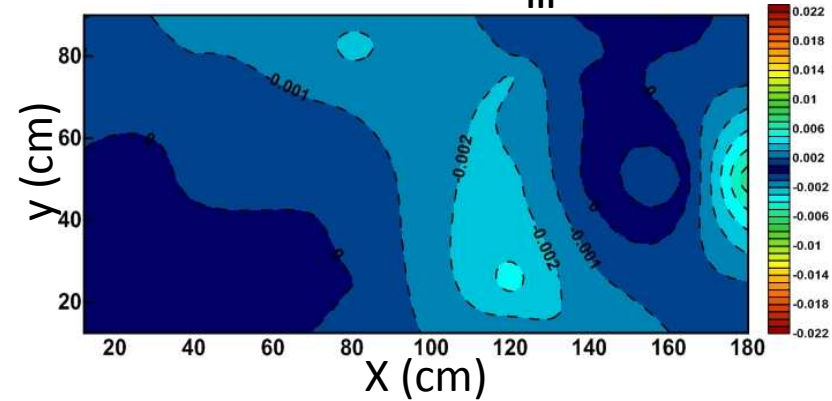
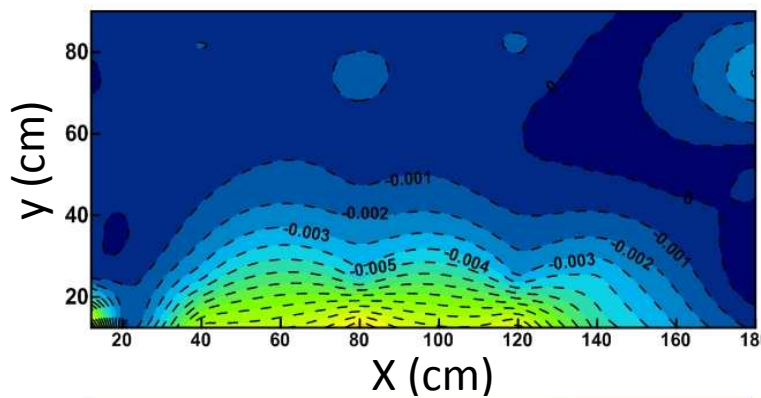
- Maximum longitudinal ($Le_{\Delta x}$)
and transversal ($Le_{\Delta y}$) eddy diameters

$(\tau_{xy}/\rho V_o^2)$ - Reynolds shear stress (dimensionless)

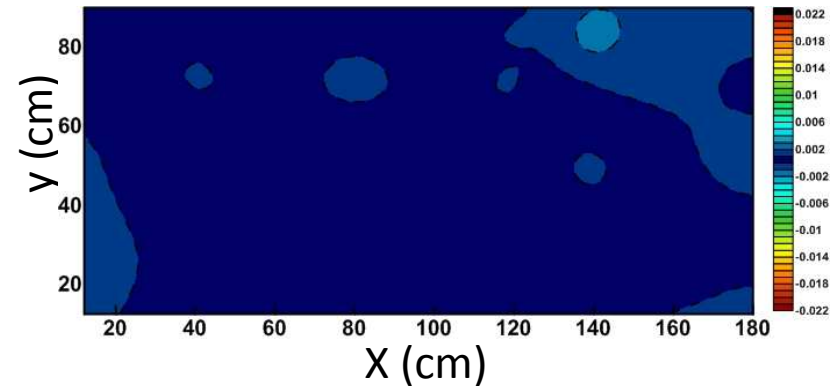
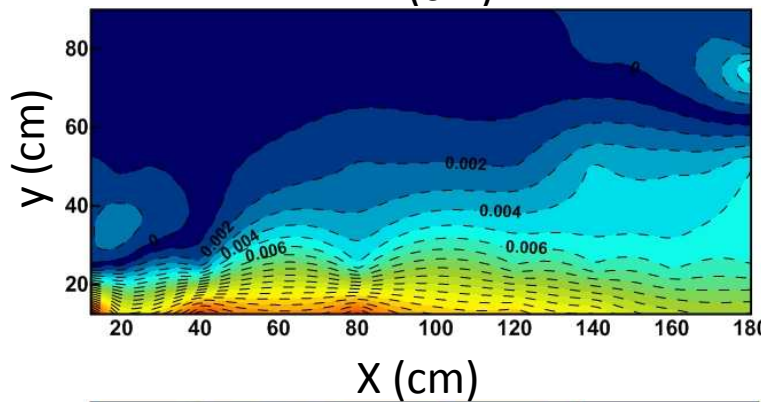
$Z=0.25h_m$

$Z=0.80h_m$

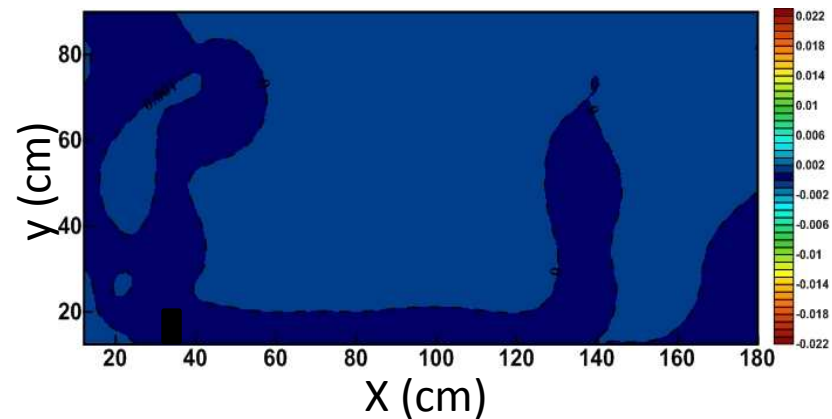
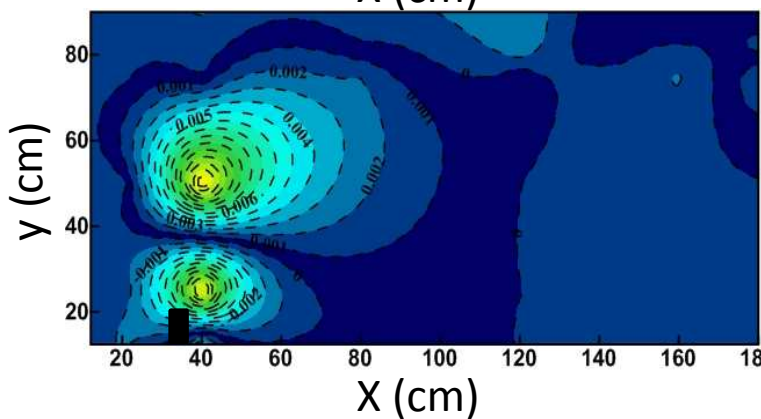
Offset
orifices



Straight
orifices

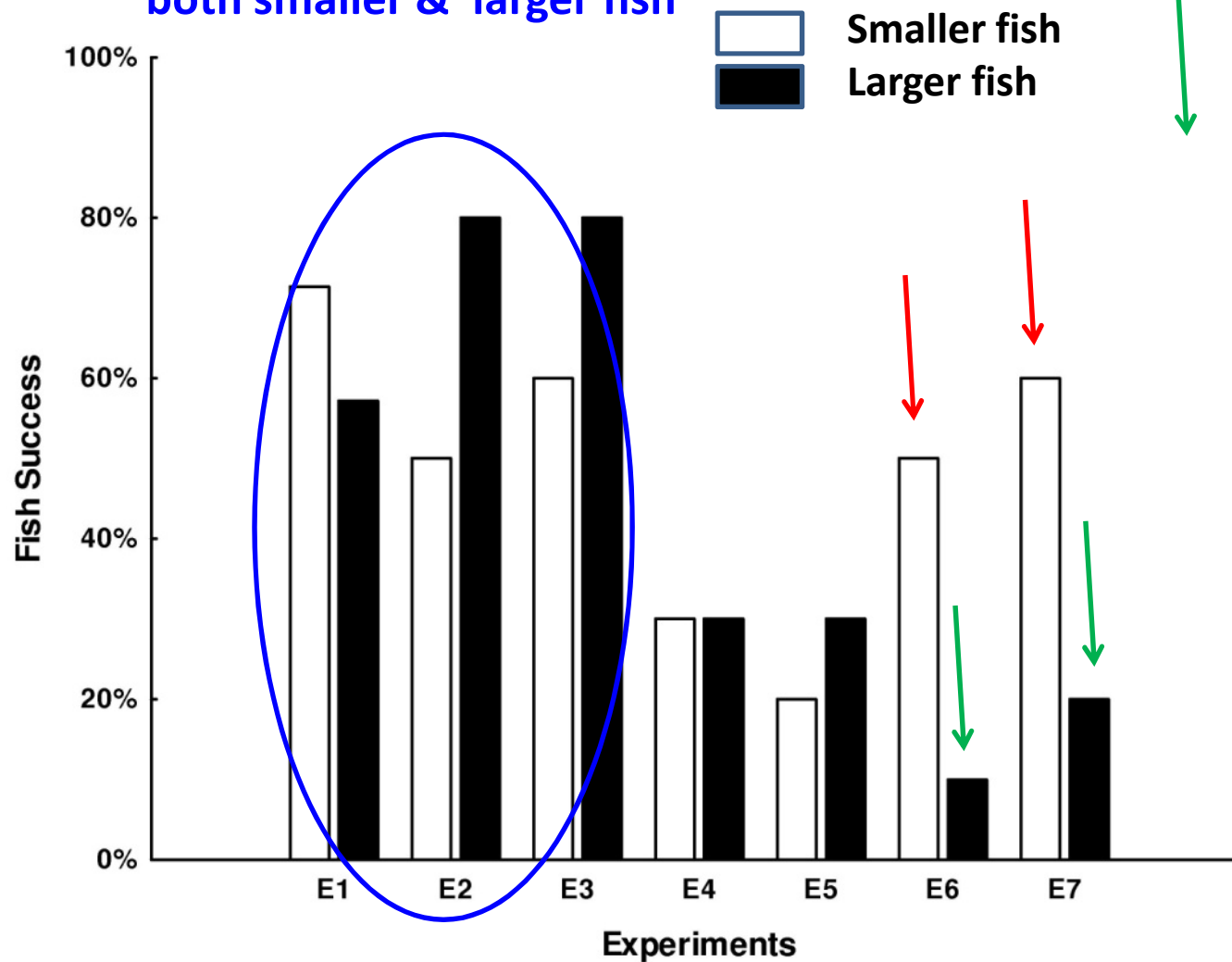


Straight orifices
with a bar



Passage Success

NOTE: Most succesful for both smaller & larger fish



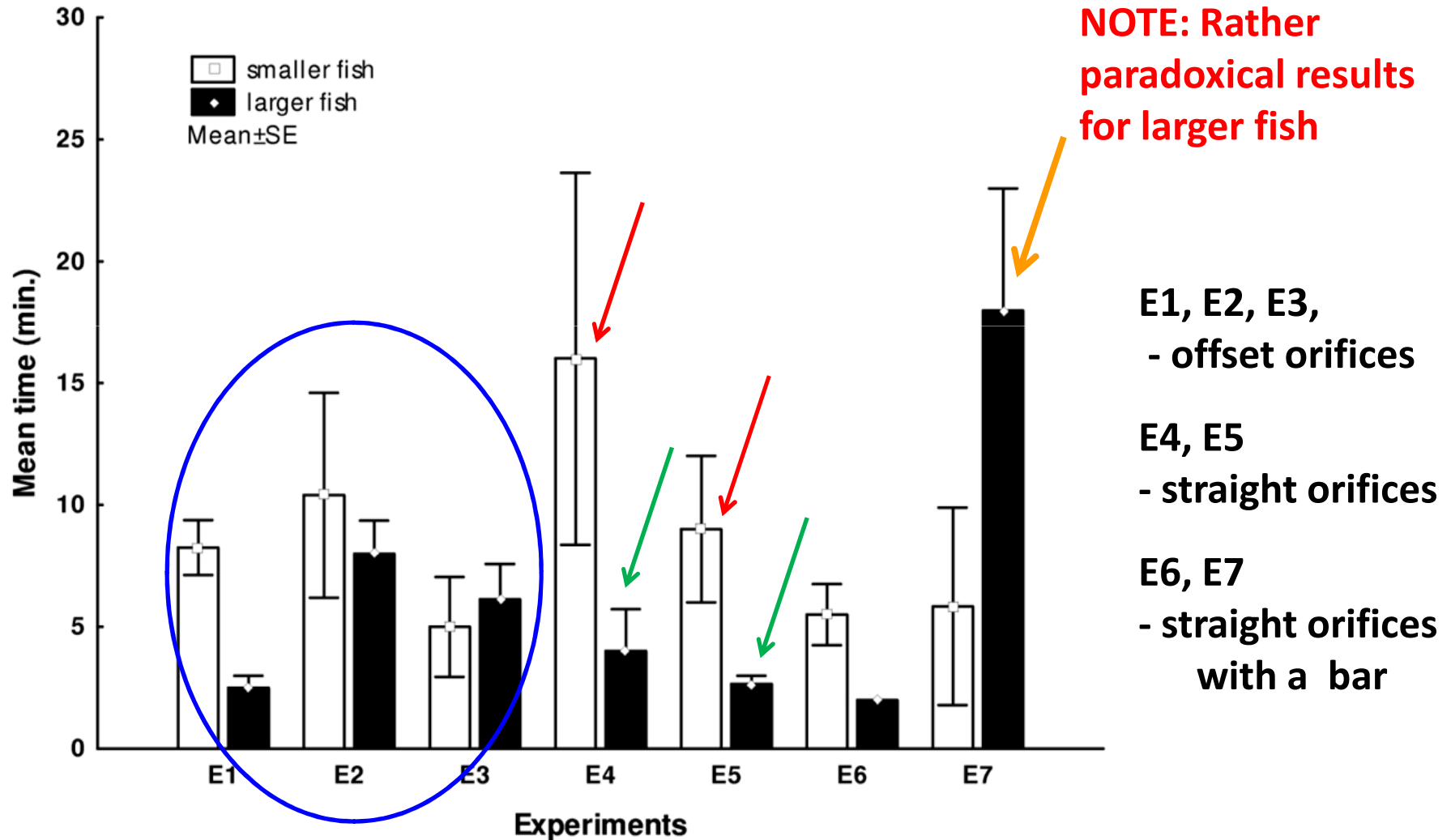
NOTE: Rather paradoxical results for larger fish

**E1, E2, E3,
- offset orifices**

**E4, E5
- straight orifices**

**E6, E7
- straight orifices
with a bar**

Time of passage



Fish behaviour x turbulent flow kinematics

Spearman rank test : *P<0.05; **P<0.01; ***P<0.001

Configuration	Fish size-class	Dependent variable	N	Spearman rank r	P-value
Offset orifices	Smaller fish	TKE (m ² /s ²)	20	-0.42	0.003**
		$ \rho u'v' $ (N/m ²)	20	-0.43	0.003**
		TI	20	-0.45	0.001**
	Larger fish	$ \rho u'v' $ (N/m ²)	20	-0.33	0.025*
Straight orifices	Larger fish	$ \rho u'v' $ (N/m ²)	20	0.37	0.039*
Straight + bar orifices	Smaller fish	$ \rho u'v' $ N/m ²)	20	0.52	0.002**
	Larger fish	v (m/s)	20	-0.38	0.034*
		$ \rho u'v' $ N/m ²)	20	0.4	0.026*

Fish behaviour x turbulent flow kinematics

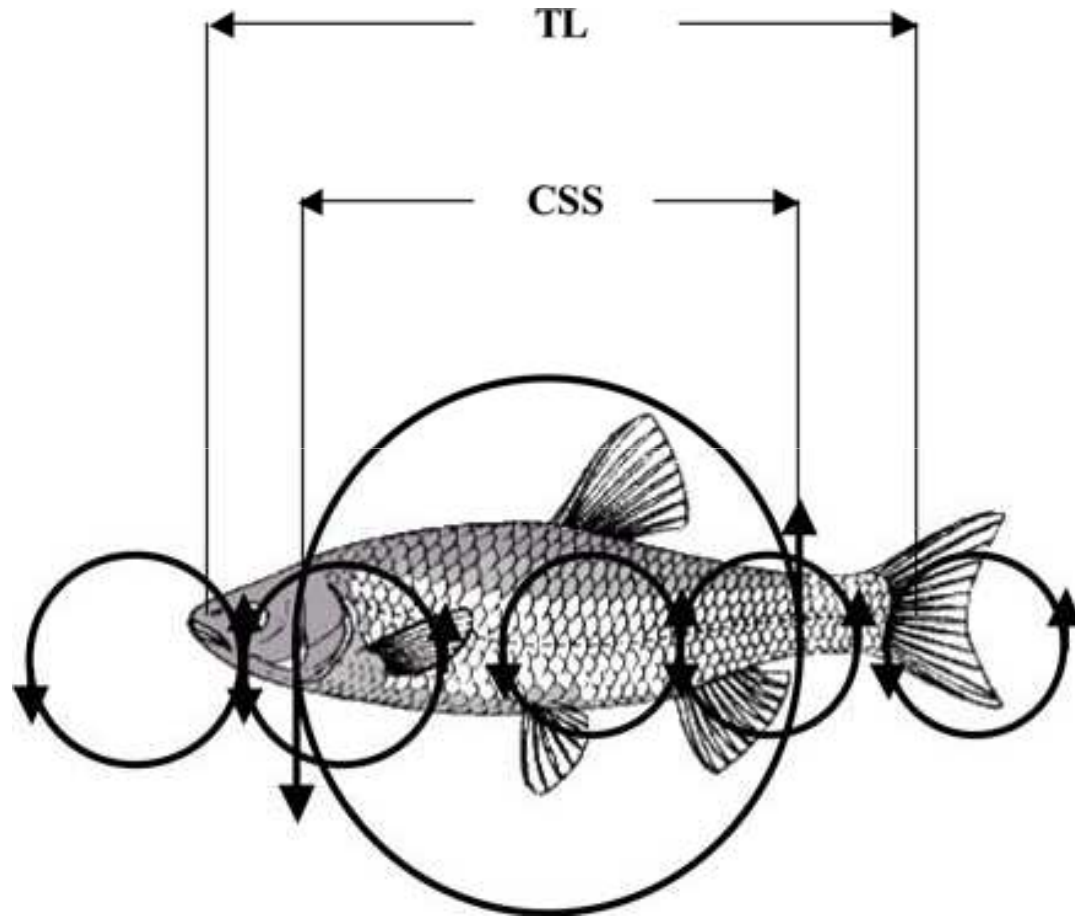
Forward stepwise regression

D, Durbin–Watson Statistics

What about fish behaviour
in straight orifices with a bar???

Configuration	Variable	F-test	r^2	D
Offset orifices				
Smaller fish				1.86
	TI	7.77**	0.15	
	$ \rho u'v' $	4.96*	0.24	
Larger fish				1.43
	$ \rho u'v' $	4.66*	0.09	
Straight orifices				
Larger fish				1.25
	$ \rho u'v' $	7.06*	0.2	

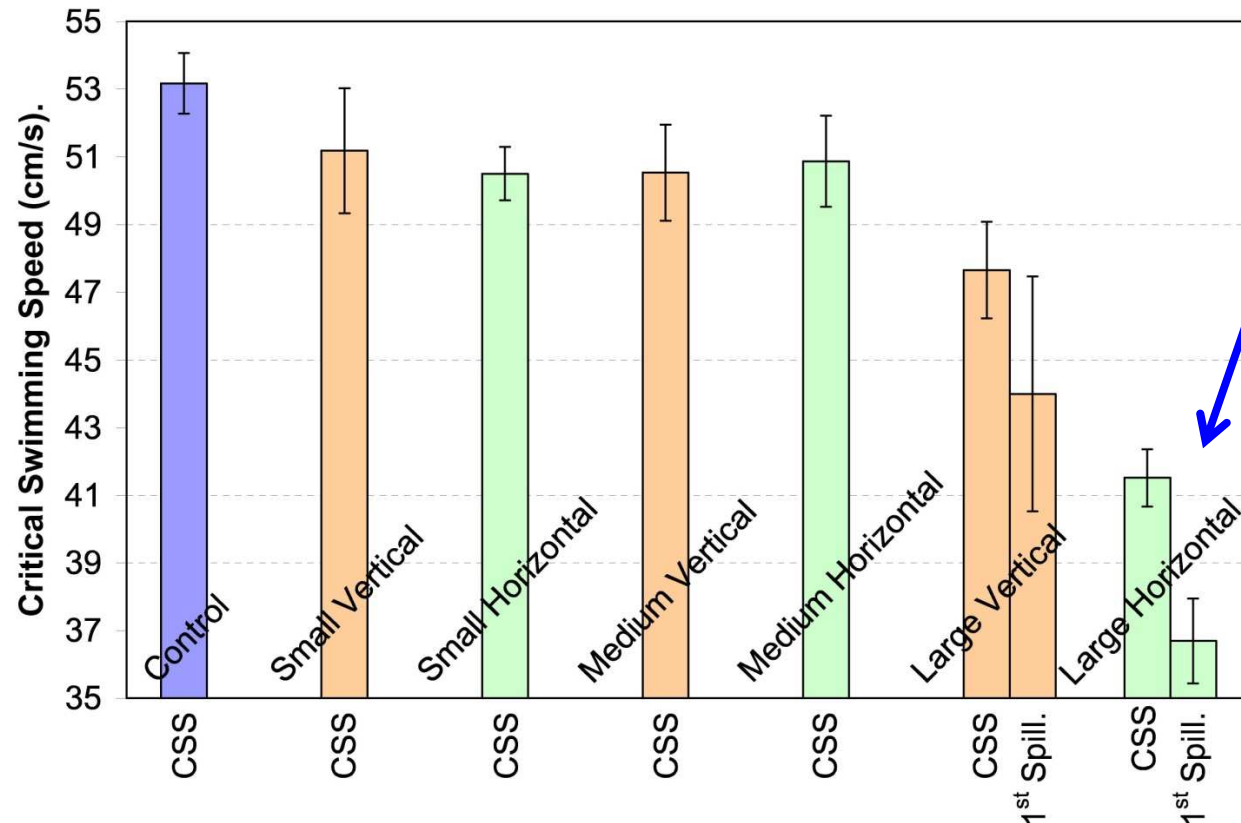
Effect of eddy size



Water turbulence swirls affect fish position and swimming if they are comparable with the fish body size. Critical swirl size (CSS) is approximately equal to 0.7 of the fish body length (TL)

Pavlov, Mikheev, Lupandin and Skorobogatov 2008; Lupandin, 2005;
Pavlov, Lupandin and Skorobogatov 2000.

Effect of eddy size



Creek chub (*Semotilus atromaculatus*); TL= 12.2 cm

Eddies that are horizontal in orientation, rotate rapidly and have a diameter approximately equal to the fish length are expected to cause the greatest stability challenges for a free swimming fish.

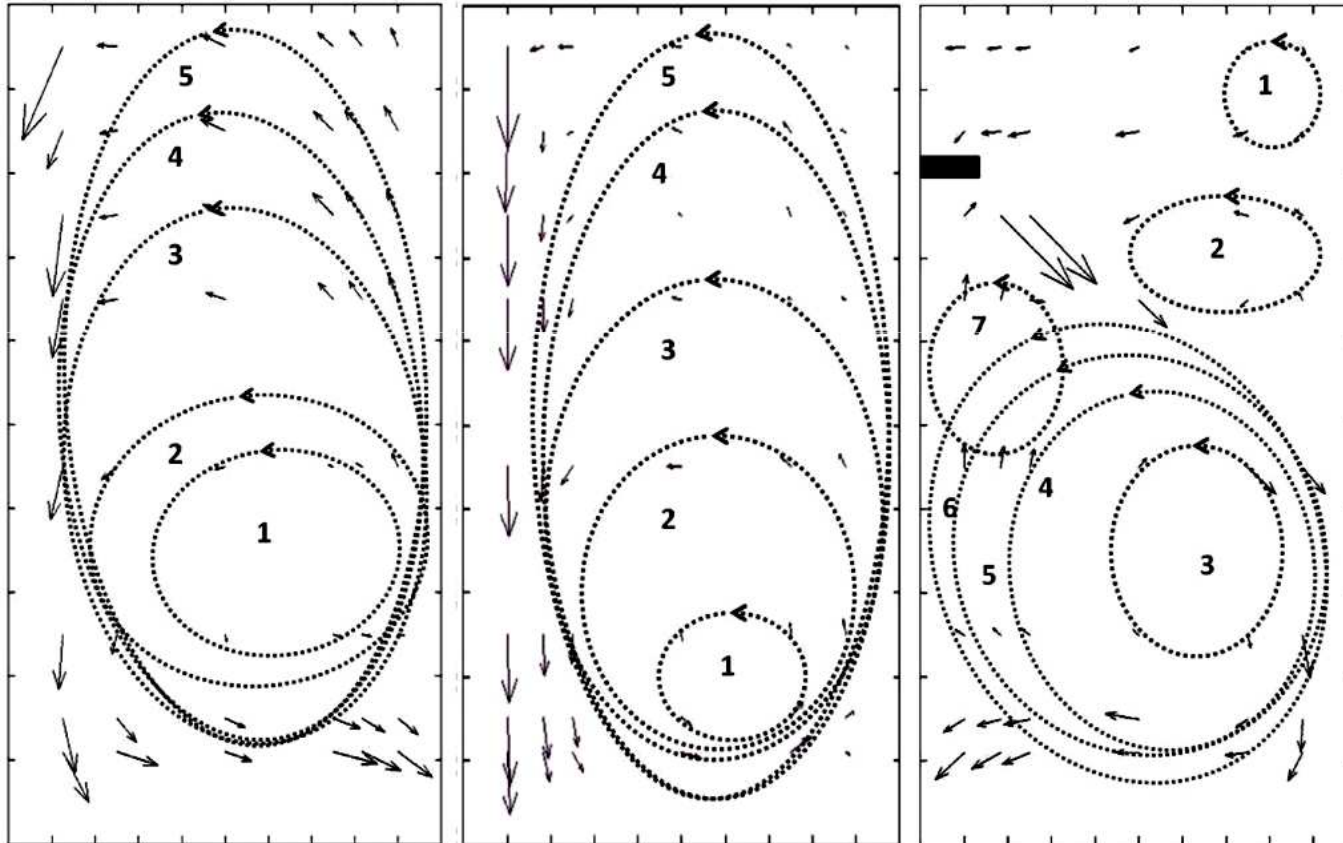
Eddy distributions

At $Z=0.25h_m$

1. Offset orifices

2. Straight orifices

3. Straight orifices
with a bar

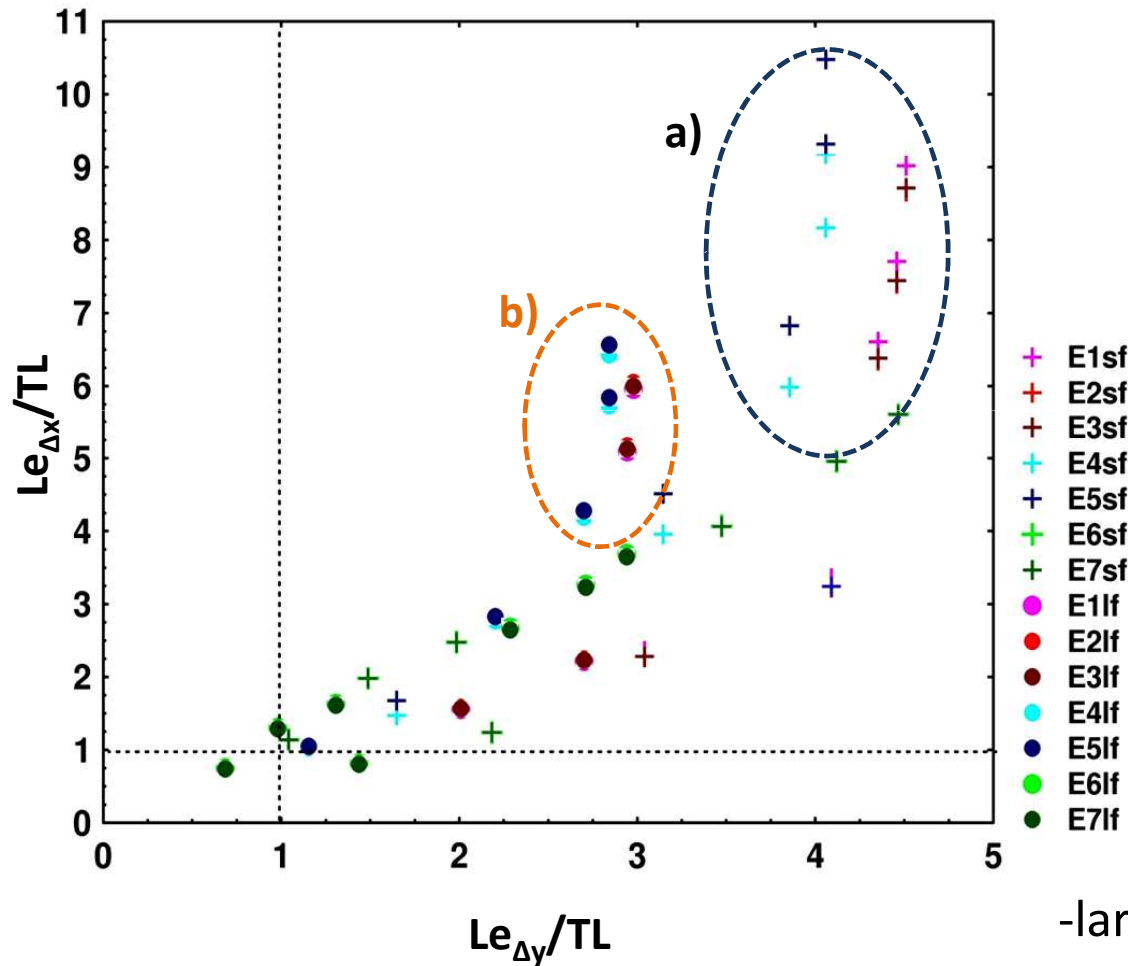


Was fish behaviour impacted by turbulent eddies???

Particularly in experiments with straight orifices with a bar?

Eddy size vs. fish length (L_e/TL)

Fish behaviour observed



a) $Le/TL_{sf} > 1$ (+)

- Offset orifices

- small fish disorientation

- Straight orifices

- small fish disorientation

- small fish drifted and were dragged to d/s pool

b) $Le/TL_{if} > 1$ (•)

- Offset orifices

- large fish display negligible disorientation

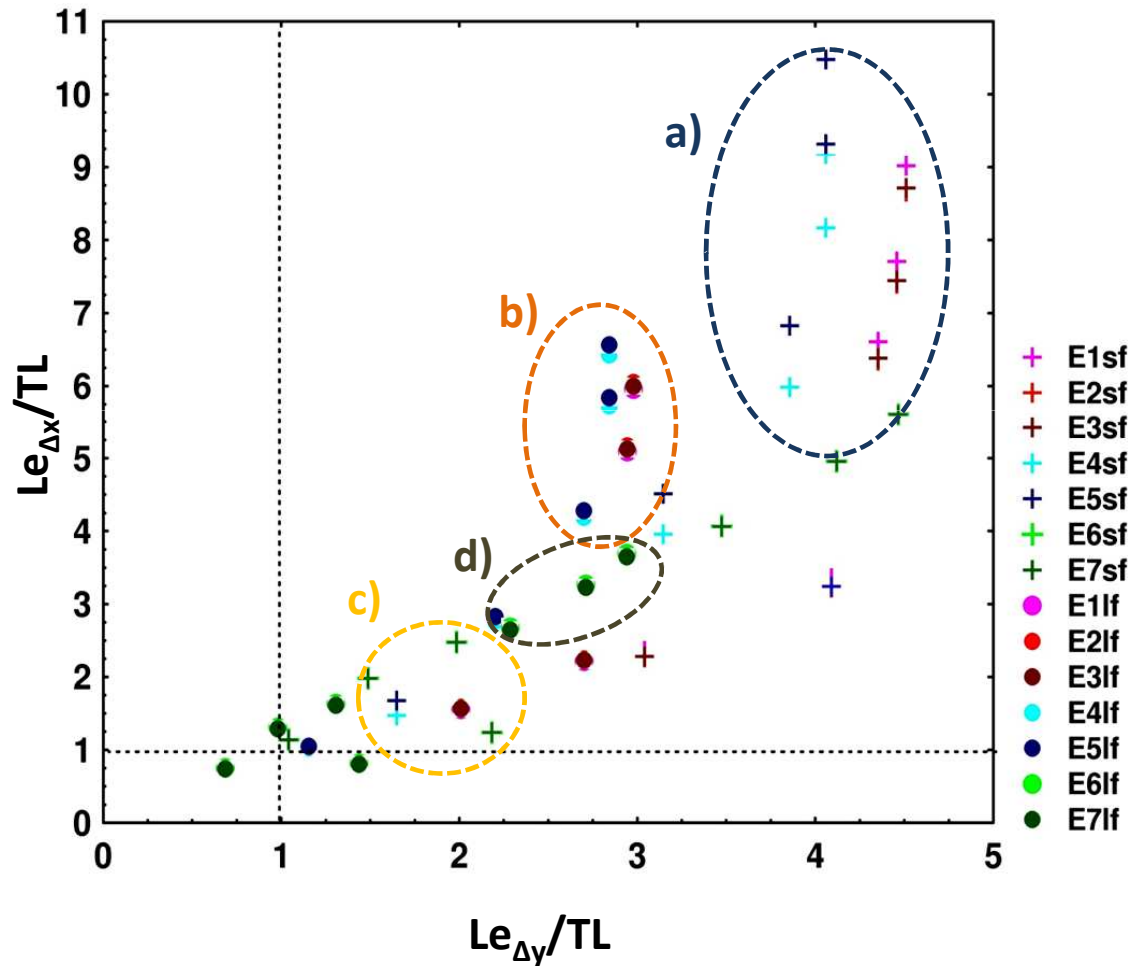
- Straight orifices

- large fish negligible disorientation

- most fish re-establish orientation and successfully ascend

Eddy size vs. fish length (L_e/TL)

Fish behaviour observed



c) $1 < Le/TL_{sf} \leq 2.5$ (+)

• Straight orifices with a bar
 -small fish swim steadily through eddies

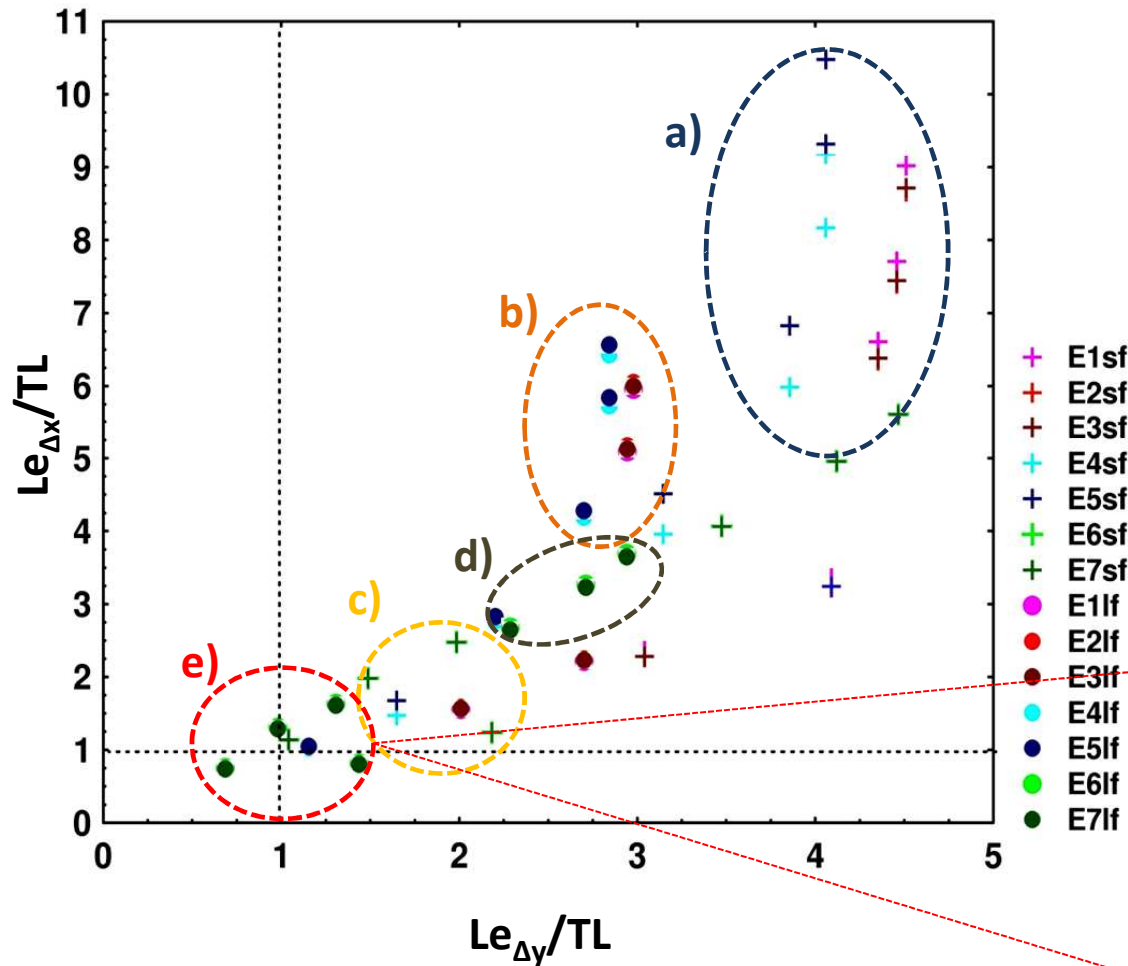
-small fish disorientated but rapidly adjusted body stability and found route to ascend successfully

d) $Le/TL_{lf} > 1$ (•)

• Straight orifices with a bar
 -large fish experience some disorientation and loss of stability control

Eddy size vs. fish length (L_e/TL)

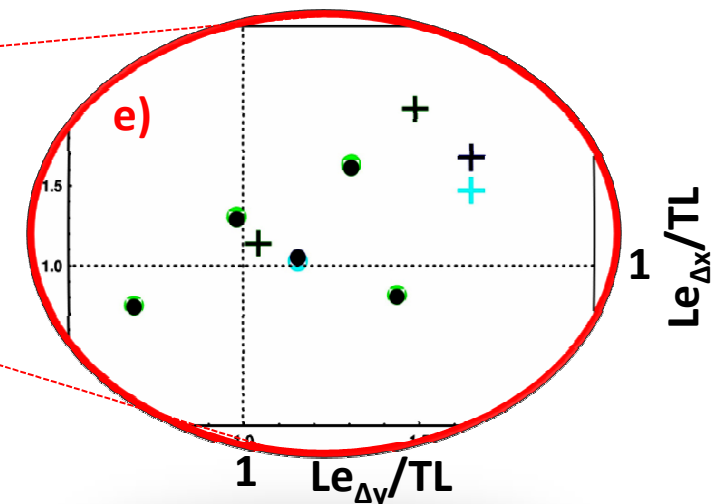
Fish behaviour observed



e) $L_e/TL_{lf} \approx 1$ (•)

• Straight orifices with a bar
 -large fish **lost body stability** and were seen to spread their **pectoral fins** in an attempt to **stabilize** body position

-most large fish were dragged to d/s pool



Conclusions

- **Offset orifice arrangement more efficient for upstream passage of Iberian barbel (highest passage success and lower transit times);**
- **Reynolds shear stress was the main factor among all the hydraulic variables analyzed, which explained passage success and fish transit times in experiments with offset and straight orifice arrangements;**
- **In experiments with straight orifices with a deflector bar, eddy size appeared to have affected fish behaviour the most, particularly the larger fish;**

Conclusions

- **Reynolds shear stress** and **eddy size**, which can vary widely with fishway pool geometry, could affect upstream fish passage.
- Further research is needed on the range of fish responses to local hydrodynamics, which are highly variable and depend on species and individual size.

Thank you



Leonardo da Vinci (1452-1519) : old man and vortices