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# Assessing multi slot versus single slot pool-type fishways suitability for potamodromous cyprinids: An experimental approach using numerical modelling and fish

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# ASSESSING MULTI SLOT VS SINGLE SLOT POOL-TYPE FISHWAYS SUITABILITY FOR POTAMODROMOUS CYPRINIDS: AN EXPERIMENTAL APPROACH USING NUMERICAL MODELLING AND FISH

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CIVIL ENGINEERING RESEARCH AND INNOVATION FOR SUSTAINABILITY
TÉCNICO LISBOA

INSTITUTO SUPERIOR DE AGRONOMIA
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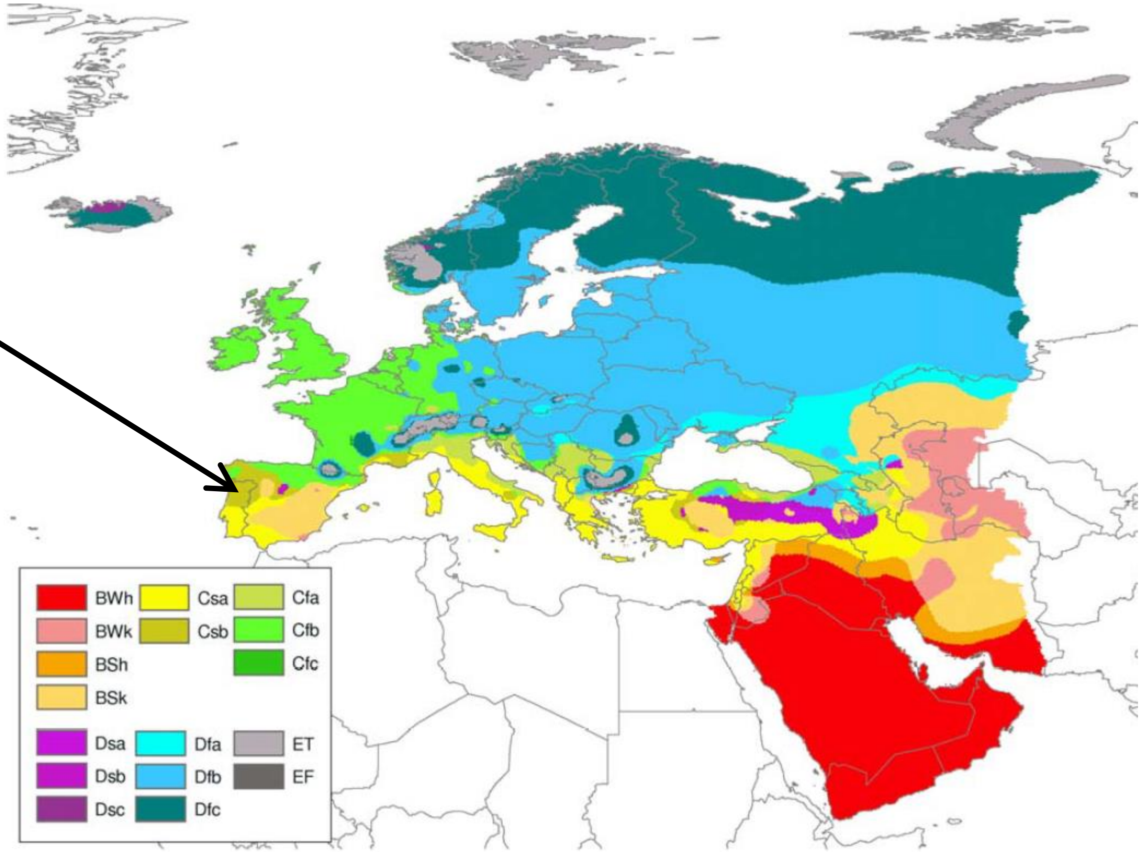
# Motivation

Portugal

**Csa –** Temperate, dry and hot summer mediterranean climate

**Csb –** Temperate, dry and warm summer mediterranean climate




**Köppen-Geiger climate type map of Europe (Peel et al., 2007)**

**Mediterranean type river systems with extended low flow periods**

**Preference for fish passages solutions with lower water consumption**

# Introduction

## Orifice and notch pool-type fishways

**Quite common in Southwest Europe**

**Relatively low water requirement**

**Some maintenance problems**

Notch clogging

Orifice clogging

# Introduction

## Vertical Slot Fishway (VSF)

- ✓ **Fish can swim through the slot at any desired depth.**
- ✓ **Remain operational for a wide range of water depth.**
- ✓ **Less susceptible to clogging.**

⇩

**But larger flow discharges are required relatively to alternative orifice and notch configurations**

**VSF at Coimbra dam**

# Introduction

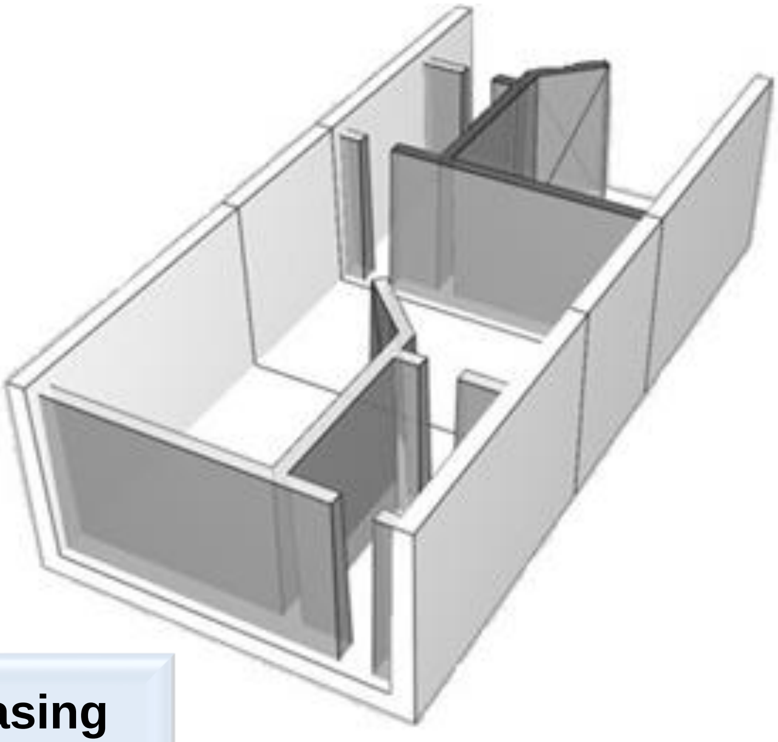
## Multi-Slot Fishway (MSF)

**Variation on the VSF, based on**

**Enature® fishpass , Tauber & Mader, 2009,**

**Mader & Tauber, 2010**

**www.maba-fishpass.com;**
**www.fischaufstieg.at**



**Splits the drop between pools (~*ΔH/2*), increasing head loss coefficient per pool, which means smaller discharges for a specific slot width and equal pool mean depth**

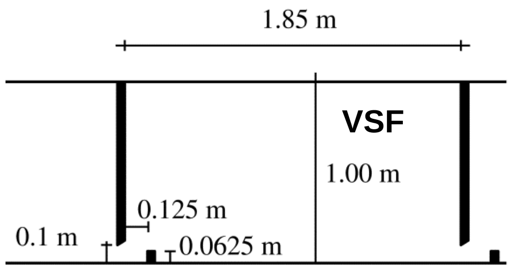
# Objective

**Simulate and compare the hydrodynamics and**

**assess the <u>hydraulic suitability</u>**

**for different fish species**

**of a widely used VSF configuration**



# Objective

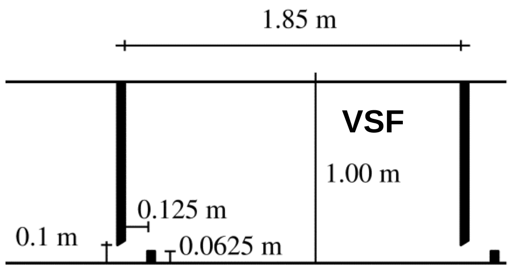
**Simulate and compare the hydrodynamics and**

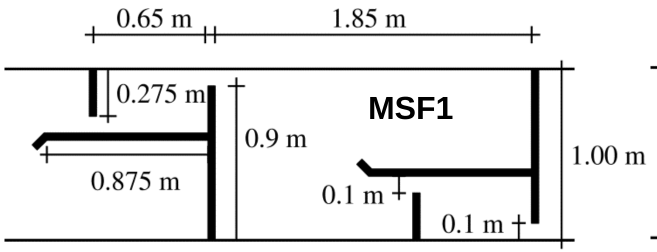
**assess the <u>hydraulic suitability</u>**

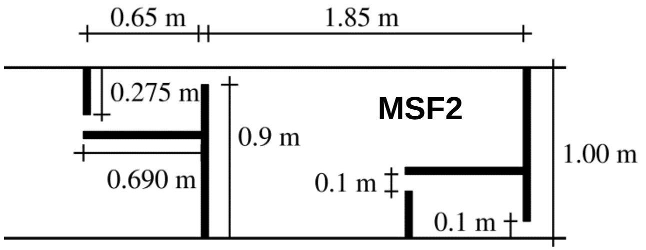
**for different fish species**

**of a widely used VSF configuration**

**and of two MSF variants using 3D modelling**



# Materials and Methods

## Experimental setup


10 m long, 1.00 m wide and 1.20 m high

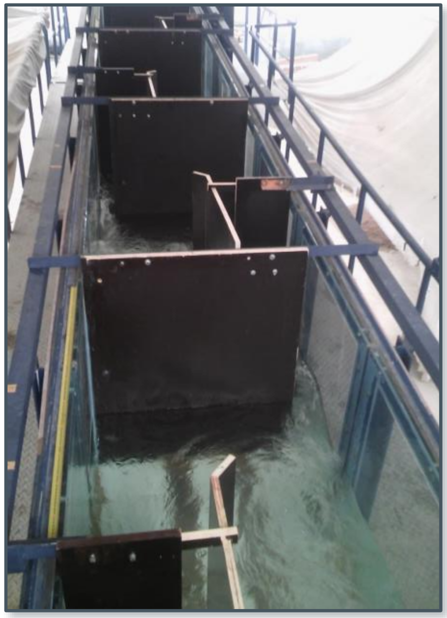
hydraulic measurements and tests with fish

# Materials and Methods

## Velocity Measurements

VSF

MSF1

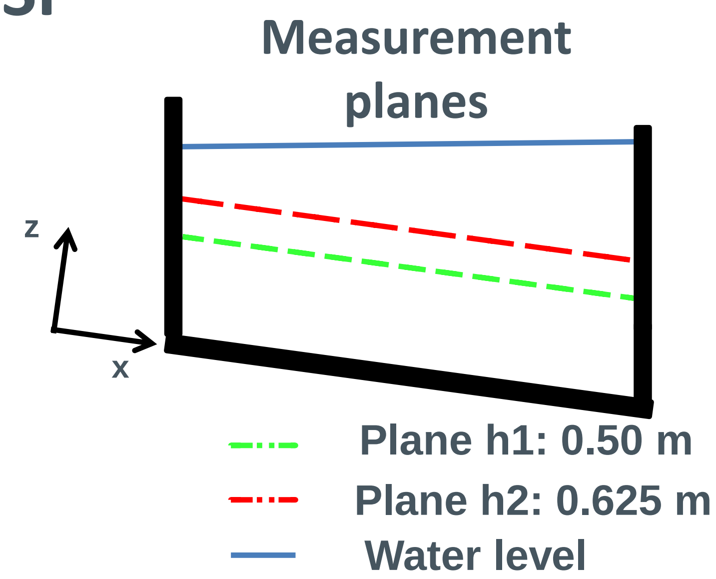


- **6 pools;**
  **each 1.85 m long x 1.00 m wide x 1.20 m high ;**
- **slots** width = **0.10 m wide;**
- **s = 8.5%;    Δh = 0.16 m;    $h_m$ = 0.80 m ;**
- **Q(VSF) = 81 l/s;    Q(MSF1) = 56 l/s.**

# Materials and Methods

## Velocity Measurements

VSF



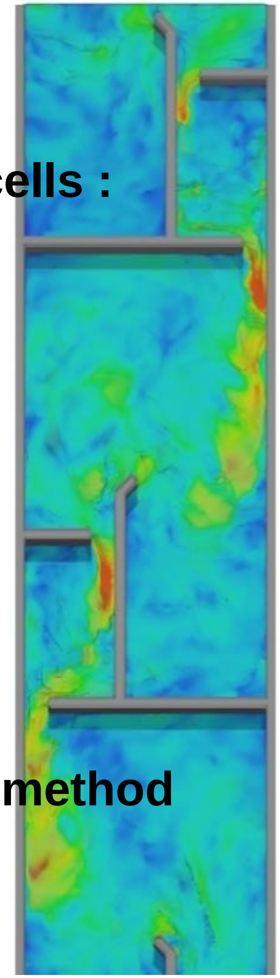

**VSF - 3D velocity components (u; v; w)**

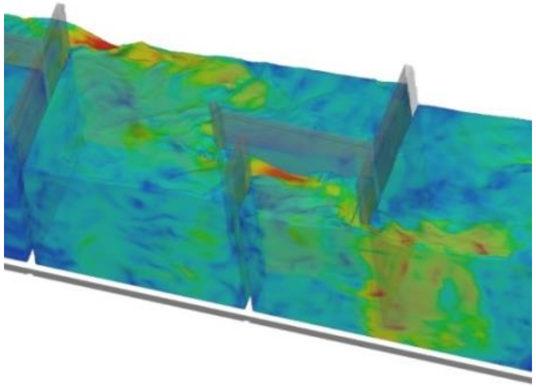
**measured with ADV in the 2nd pool**

# Materials and Methods

## Numerical model

- **FLOW-3D® was used with:**
  - ✓ **Cartesian structured mesh grid of variable-sized hexahedral cells :**
    - ➢ **4 cm mesh for the entire flume,**
    - ➢ **2 cm mesh for the cross-walls and the 2nd - 4th pool,**
    - ➢ **1 cm mesh for the VSF slots**
  - ✓ **Volume of fluid (VOF) method**
  - ✓ **Fractional Area/Volume Obstacle Representation (FAVOR™)**
  - ✓ **Turbulence model: Large eddy simulation (LES)**
  - ✓ **Second order monotonicity preserving momentum advection method**





# Materials and Methods

## Numerical model validation

| Fishway configuration | Pool mean water depth (cm) | | | Discharge ($ls^{-1}$) | | |
|---|---|---|---|---|---|---|
| | Experimental | Numerical model | Relative difference (%) | Experimental | Numerical model | Relative difference (%) |
| VSF | 80 | 81 | 1.8 | 81 | 80 | -1.3 |
| MSF1 | 80 | 83 | 4.2 | 56 | 58 | 3.3 |

# Materials and Methods

## Numerical model validation

| Fishway configuration | Pool mean water depth (cm) | | | Discharge ($ls^{-1}$) | | |
|---|---|---|---|---|---|---|
| | Experimental | Numerical model | Relative difference (%) | Experimental | Numerical model | Relative difference (%) |
| VSF | 80 | 81 | 1.8 | 81 | 80 | -1.3 |
| MSF1 | 80 | 83 | 4.2 | 56 | 58 | 3.3 |

**Maximum relative differences of ≈ 3% for flow discharges**

**and**

**≈ 4% for pool mean water depths**

**A quite good approximation between experimental and numerical results**

# Materials and Methods

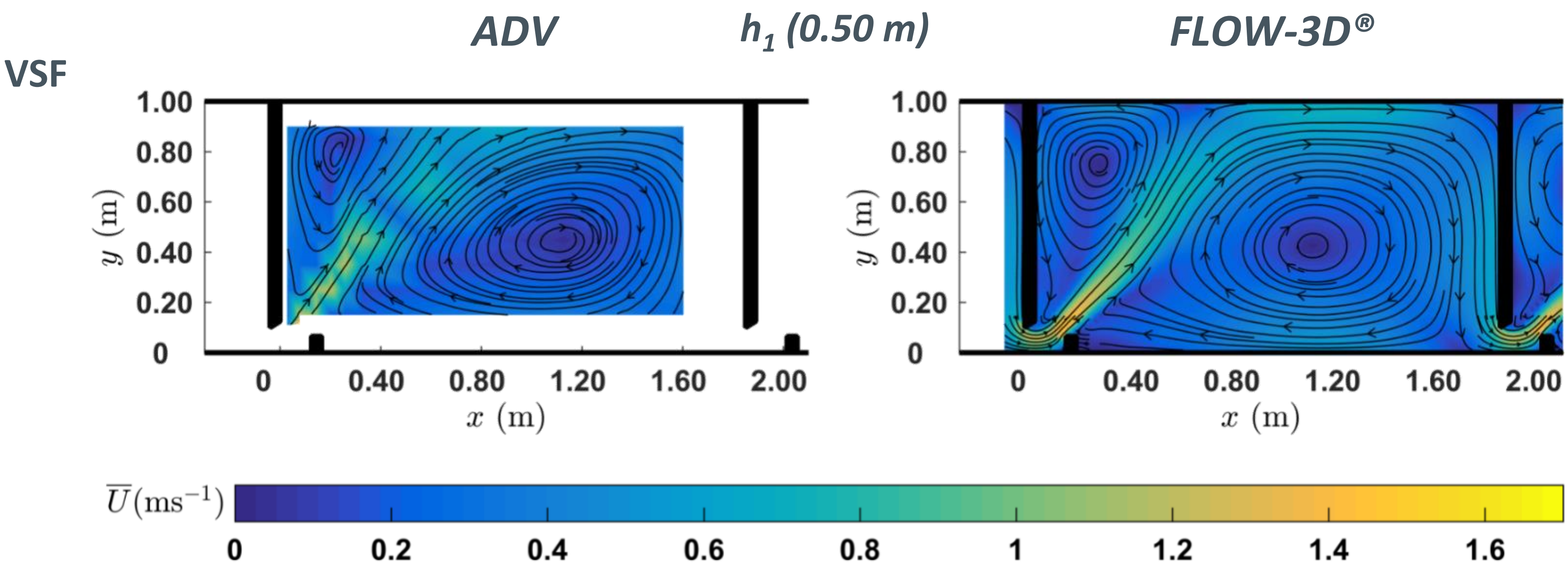
## Numerical model validation

| Fishway configuration | Discharge ($Ls^{-1}$) | Relative difference (%) |
|---|---|---|
| VSF | 80.0 | - |
| MSF1 | 57.9 | -27.6 |
| MSF2 | 63.0 | -21.2 |

**MSF operates with a <u>much smaller discharge</u>**

# Materials and Methods

## Numerical model validation



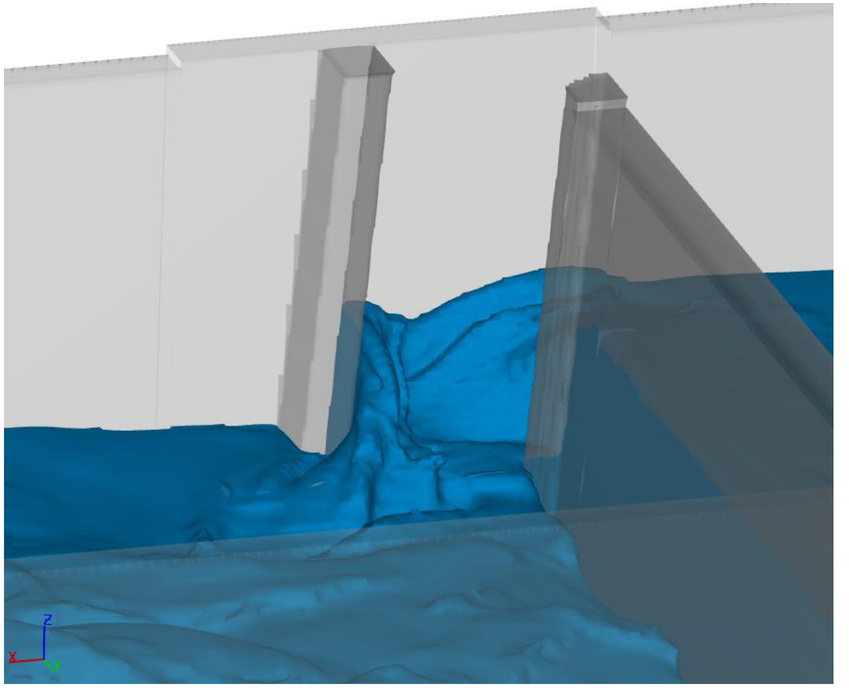

**Maximum relative differences of 5% for**

**<u>maximum and average mean velocity magnitude ($\overline{U}$)</u>**

**Low mean absolute differences for k and $|\tau_{uv}|$**

# Materials and Methods

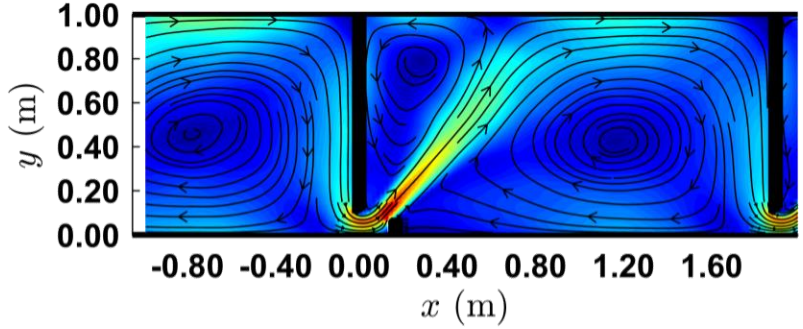
## Numerical model validation



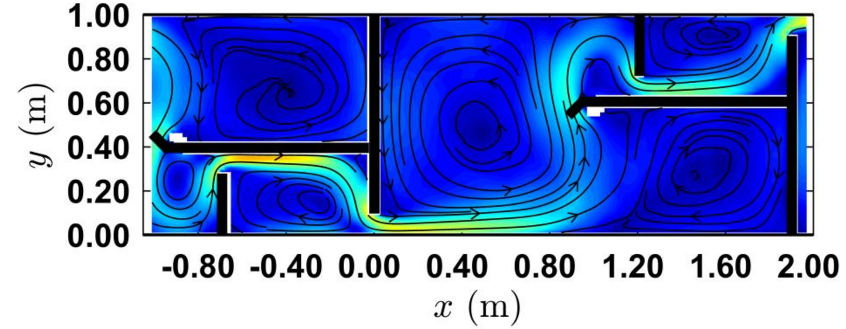
# Results

VSF

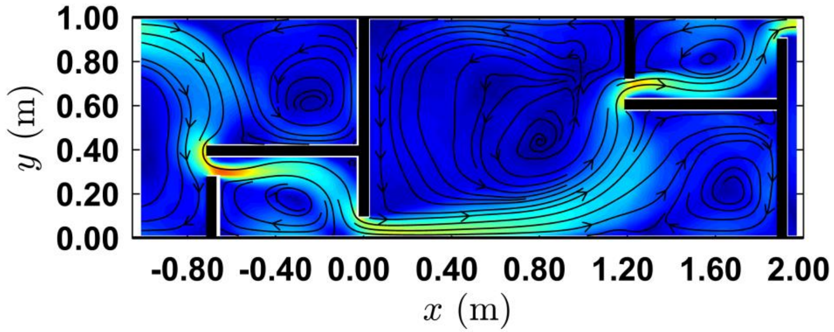
*$50\%h_m$ (0.40 m)*




MSF1




MSF2

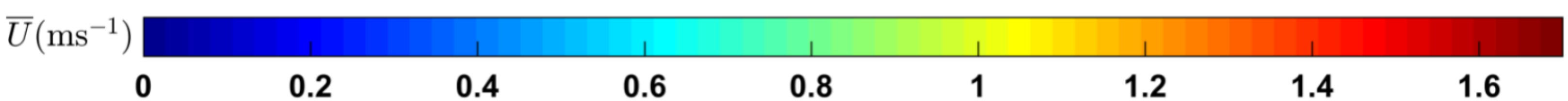



**Mean velocity magnitude in the pool ($\overline{U}$)**

**VSF** $\overline{U}_{average}$ = 0.41 $ms^{-1}$

**MSF1** $\overline{U}_{average}$ = 0.26 $ms^{-1}$

**MSF2** $\overline{U}_{average}$ = 0.24 $ms^{-1}$

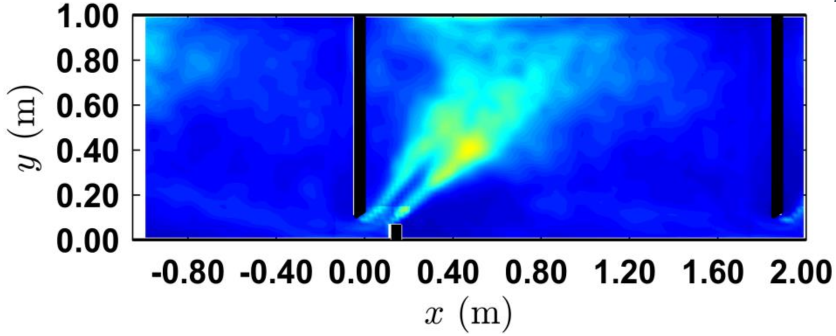



**MSF - mean velocity magnitudes are <u>much lower</u> than for the VSF**

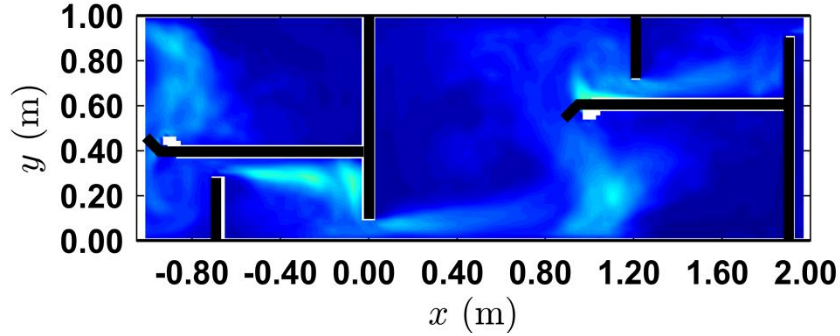
# Results

*50%$h_m$ (0.40 m)*

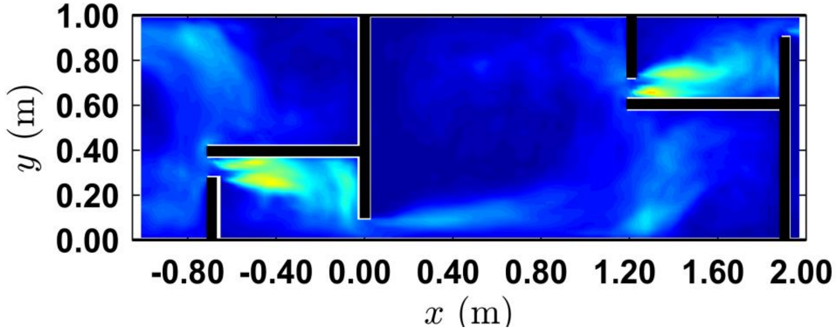
VSF




MSF1




MSF2

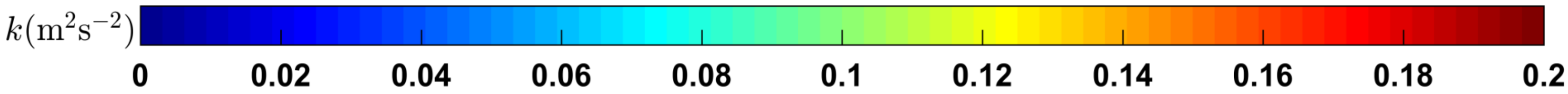



**Turbulent kinetic energy in the pool (*k*)**

**VSF** $k_{average}$ = 0.042 $m^2s^{-2}$ $k_{max}$ = 0.35 $m^2s^{-2}$

**MSF1** $k_{average}$ = 0.026 $m^2s^{-2}$ $k_{max}$ = 0.12 $m^2s^{-2}$

**MSF2** $k_{average}$ = 0.031 $m^2s^{-2}$ $k_{max}$ = 0.20 $m^2s^{-2}$



# Results

VSF

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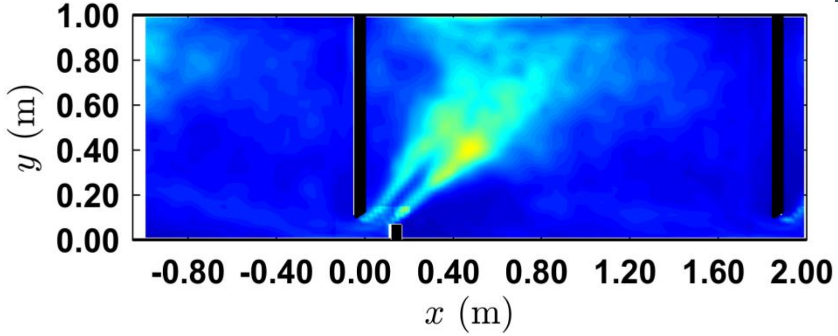
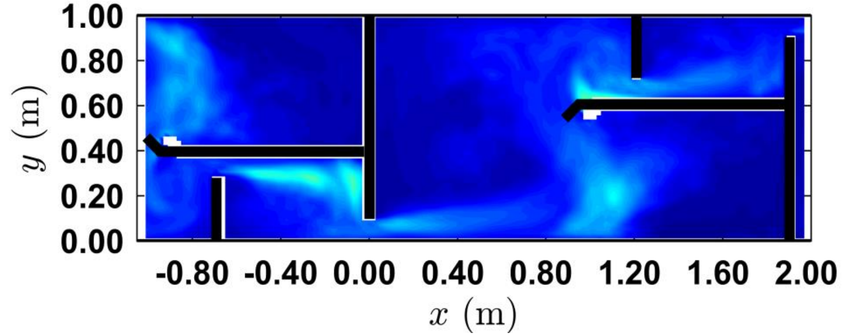
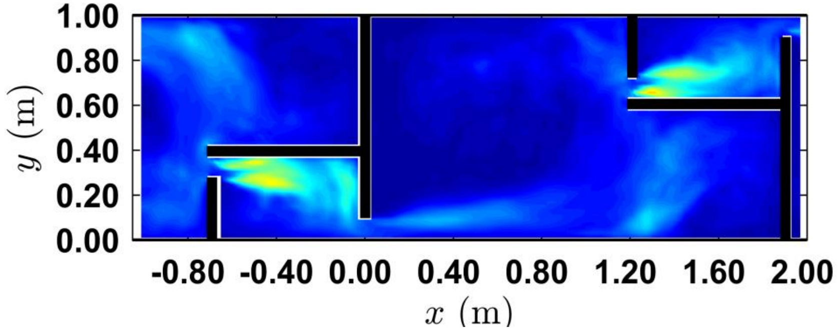



MSF1




MSF2

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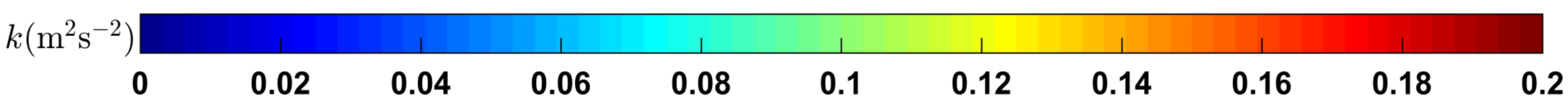



**Reynolds shear stress ($\tau_{uv}$)**

**VSF** $|\tau_{uv}|_{average}$= 8 Pa $|\tau_{uv}|_{max}$= 147 Pa

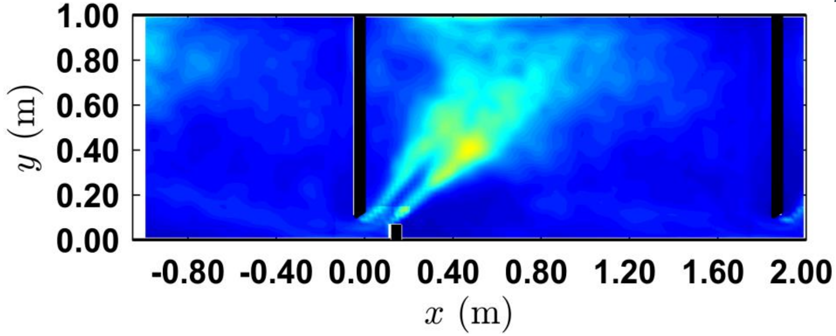
**MSF1** $|\tau_{uv}|_{average}$= 5 Pa $|\tau_{uv}|_{max}$= 52 Pa

**MSF2** $|\tau_{uv}|_{average}$= 5 Pa $|\tau_{uv}|_{max}$= 94 Pa

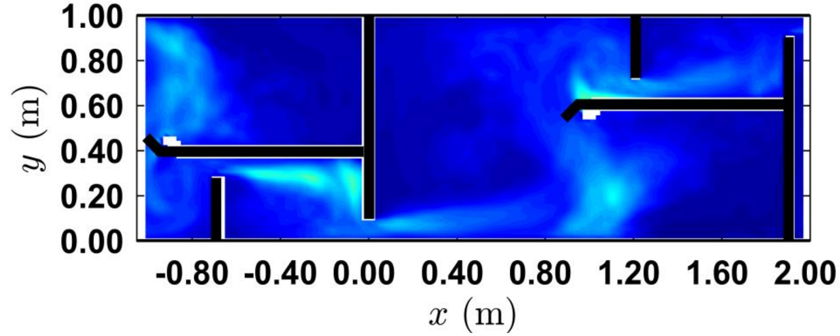
# Results

$50\%h_m$ (0.40 m)

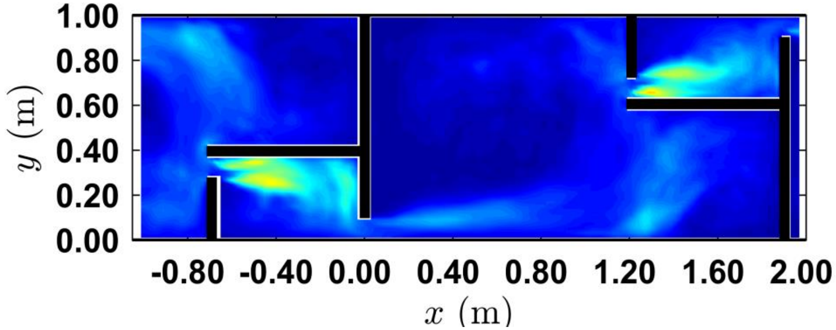
VSF




MSF1




MSF2




**Turbulent kinetic energy in the pool (*k*)**

| | | |
|---|---|---|
| VSF | $k_{average}$ = 0.042 $m^2s^{-2}$ | $k_{max}$ = 0.35 $m^2s^{-2}$ |
| MSF1 | $k_{average}$ = 0.026 $m^2s^{-2}$ | $k_{max}$ = 0.12 $m^2s^{-2}$ |
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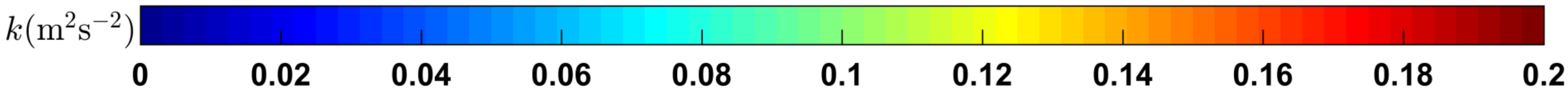


**Reynolds shear stress ($\tau_{uv}$)**

| | | |
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| MSF1 | $|\tau_{uv}|_{average}$= 5 Pa | $|\tau_{uv}|_{max}$= 52 Pa |
| MSF2 | $|\tau_{uv}|_{average}$= 5 Pa | $|\tau_{uv}|_{max}$= 94 Pa |

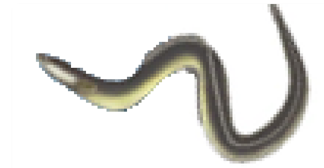
**MSF1 - volume averaged and maximum *TKE* much lower**

**MSF1 - volume averaged and maximum $\tau_{uv}$ much lower**

**MSF1 - larger areas with lower *TKE* and $\tau_{uv}$**

# Results (% pool volume)

| | $\overline{U}$ (m/s) | VSF | MSF1 | MSF2 |
|---|---|---|---|---|
| $V_{\overline{U}}$ (%) | $\leq 0.43$ (1) | 65 | **85** | 87 |
| | $\leq 0.54$ (2) | 79 | **90** | 91 |
| | $\leq 0.66$ (3) | 87 | **93** | 94 |
| | $\leq 0.78$ (4) | 90 | **96** | 96 |
| | $\leq 0.81$ (5) | 91 | **96** | 97 |
| | $\leq 1.00$ (6) | 94 | **99** | 99 |
| $V_k$ (%) | $k \leq 0.05\ m^2s^{-2}$ (5) | 73 | **94** | 85 |
| $V_{\lvert\tau_{uv}\rvert}$ (%) | $\lvert\tau_{uv}\rvert \leq 10$ Pa (5) | 77 | **83** | 85 |

(1)

Yellow-phase eels

(2)


Northern Iberian chub

(2)


Southern straight-mouth nase

(3)

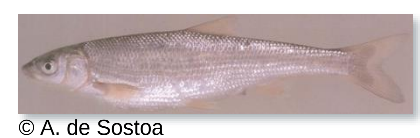

Silver-phase eels

Sea lamprey

(6)

Iberian barbel

(5)



Tagus nase

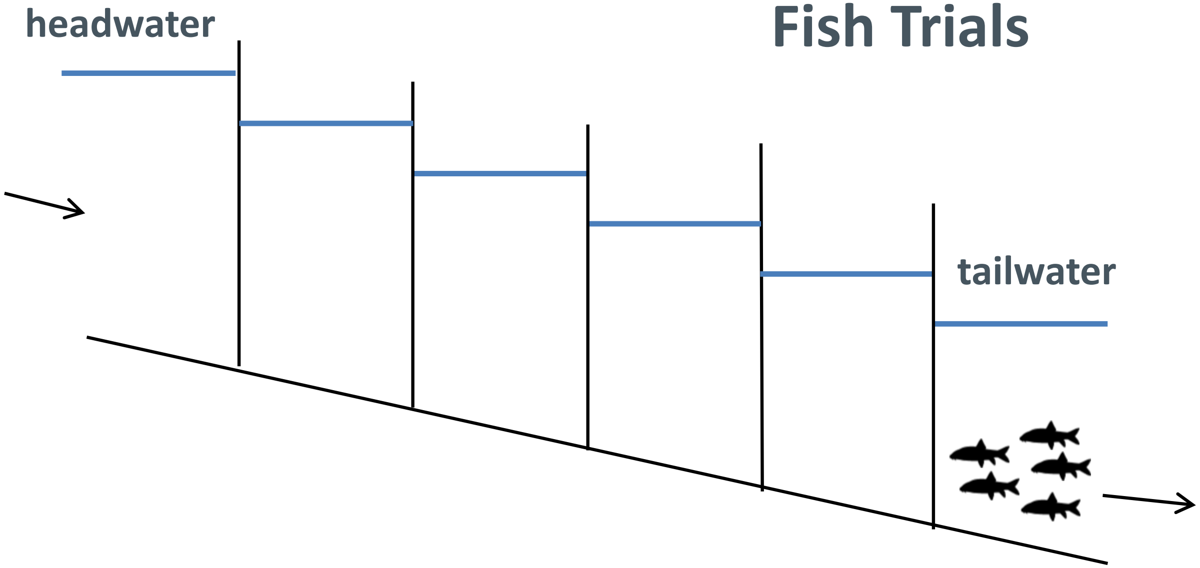
(4)

**MSFs presents larger suitable % of pool volume**

**for different Iberian species of ecological / economic interest**

# Materials and Methods

## Fish Trials



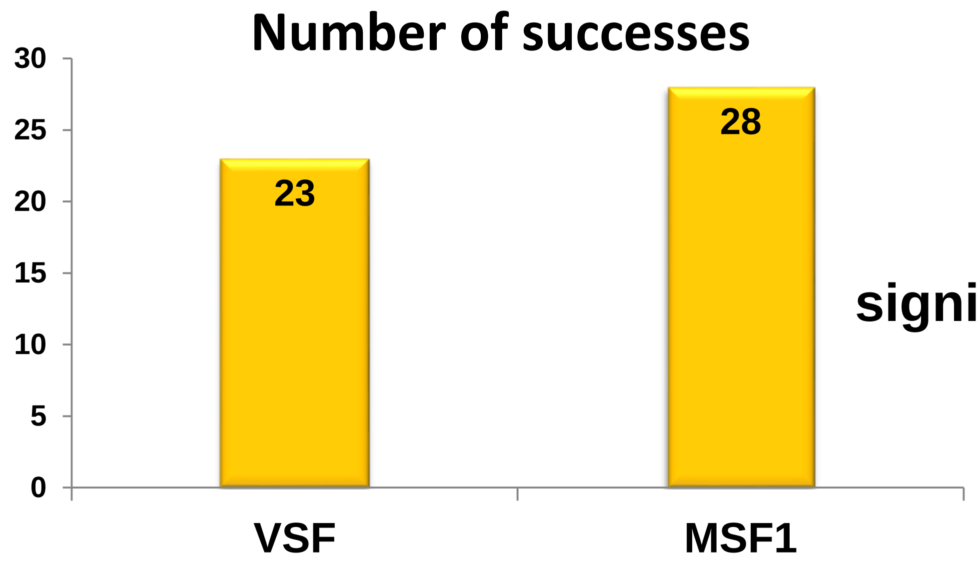


Iberian Barbel
(*Luciobarbus bocagei*, Steindachner, 1864)

| | |
|---|---|
| **Number of fish / trial** | **5** |
| **Total of trials** | **5/configuration (25 fish/configuration)** |
| **Acclimation period** | **30 minutes** |
| **Trial duration** | **90 minutes** |
| **Methods of fish behaviour observation** | **Direct observation and video recording** |
| **Assessed variables** | **Entrance time** |
| | **Entry efficiency** |
| | **Number of upstream movements** |
| | **Timing and number of successes** |

# Results

## Fish trials with barbels




**No statistically significant differences**

**<u>No significant differences, also in:</u>**

- **the time to enter**
- **the time to negotiate the fishway**
- **the entry efficiency**

# Conclusions

- ✓ **The MSF configurations require a much lower discharge to operate than the VSF, for similar mean flow depth and slot width**
- ✓ **Accordingly, the velocity, the turbulent kinetic energy, and the Reynolds shear stress values in the MSFs are much lower than the corresponding values of VSF**
- ✓ **The modelled MSF configurations presented <u>larger suitable pool volume</u> % for <u>multiple fish species</u> comparatively to VSF, thus MSF could be <u>less selective</u>**
- ✓ **Numerical modelling complemented with laboratory fish experiments can be an important tool to develop cost-effective fishways**

Quaresma AL, Romão F, Branco P, Ferreira MT & Pinheiro AN (2018). *Multi slot versus single slot pool-type fishways: a modelling approach to compare hydrodynamics*. Ecological Engineering 122: 197-206

Romão, F., Branco, P., Quaresma A.L., Amaral, S. & Pinheiro, A.N. (2018). *Effectiveness of a multi-slot vertical slot fishway versus a standard vertical slot fishway for potamodromous cyprinids*. Hydrobiologia 816: 153-163

# Acknowledgments

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**Paulo Branco** (SFRH/BPD/94686/2013) was funded by a post-doctoral grant from **FCT**. **José Maria Santos** was funded by a post-doctoral grant (MARS/BI/2/2014) from the **MARS project** (http://www.mars-project.eu/) and is presently the recipient of a **FCT** researcher contract (IF/00020/2015).

A special thanks to the **staff of LNEC** for all the support during the experiments

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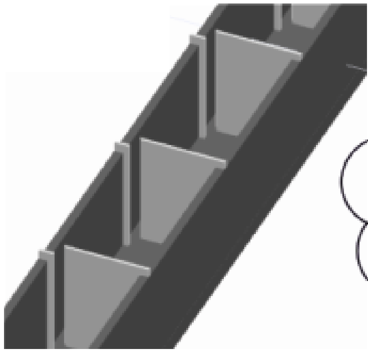
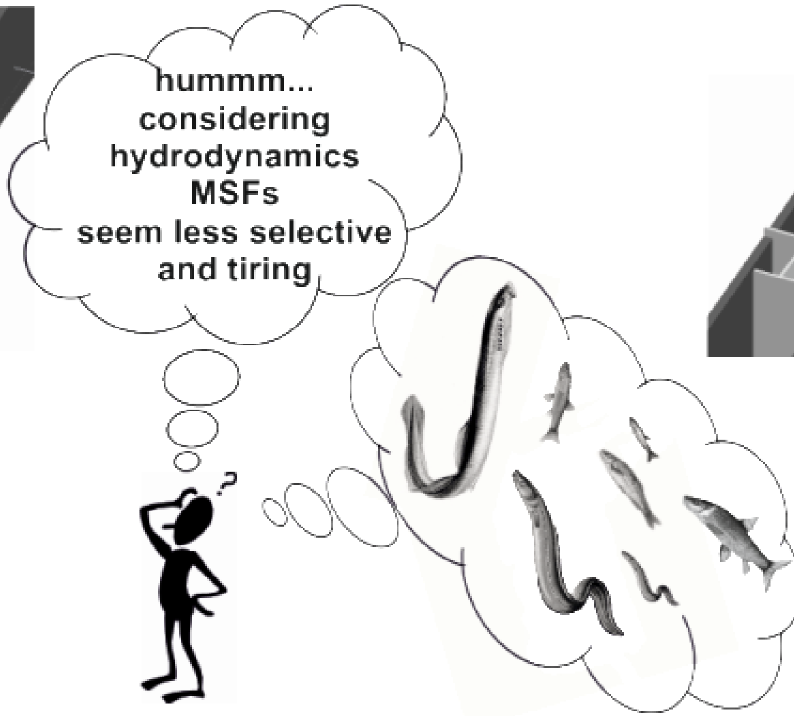
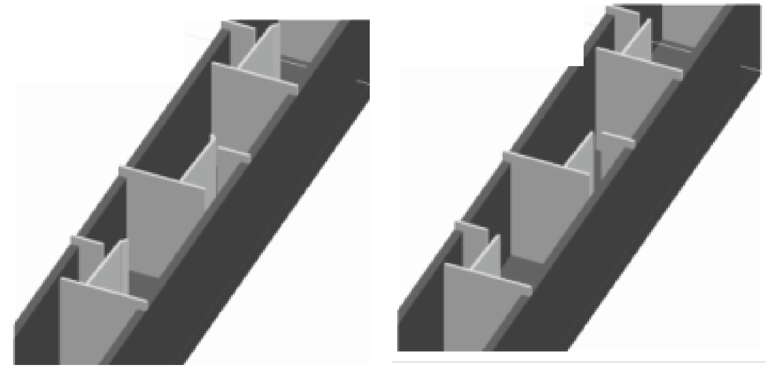
cef Centro de Estudos Florestais

# Thank you for listening



VSF



MSFs

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# Objective

**Simulate and compare the hydrodynamics and**

**assess the <u>hydraulic suitability</u> for different fish species**

**of a widely used VSF configuration and of two MSF variants**

**using 3D CFD modelling**