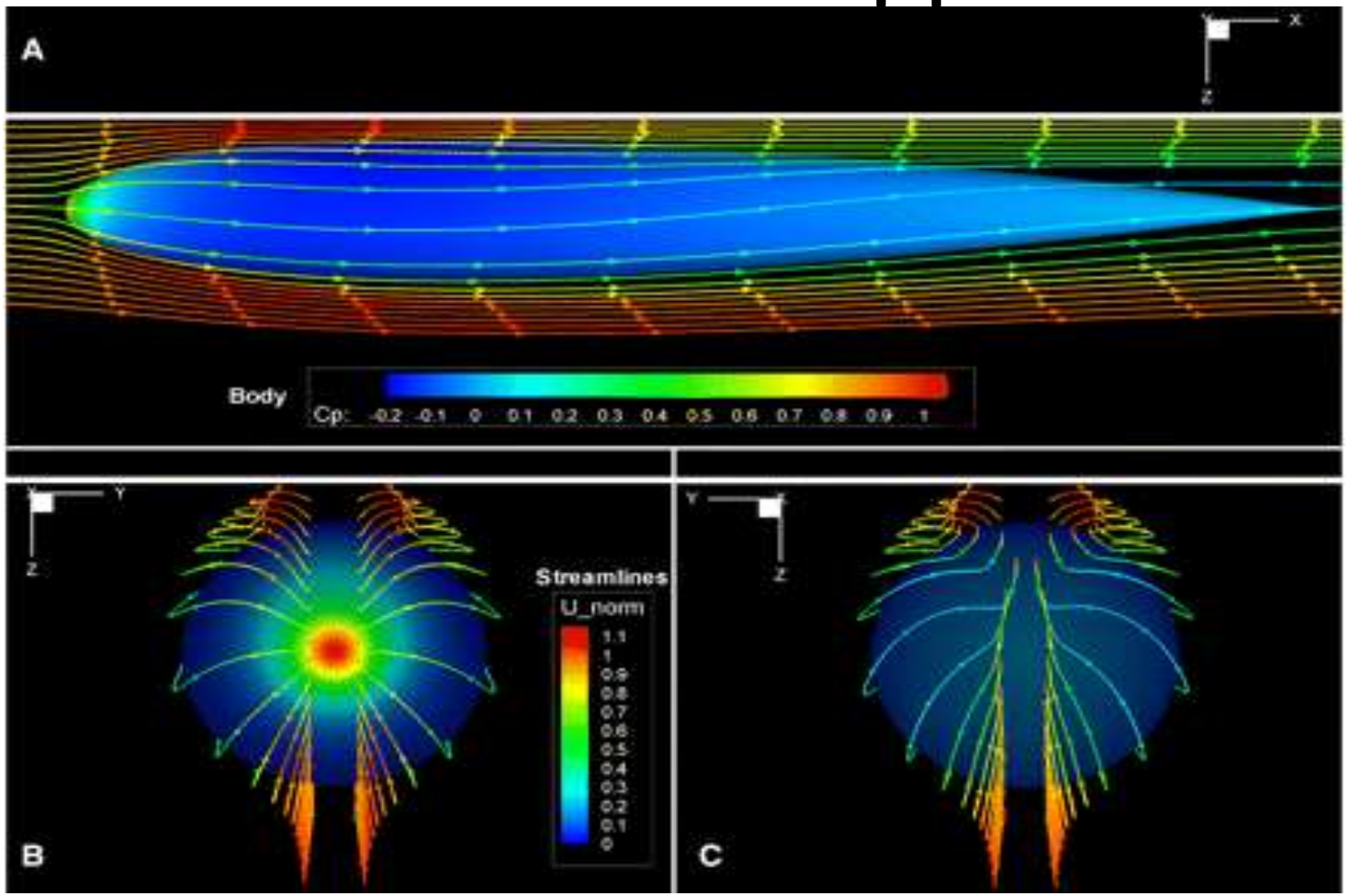
Fish swimming and hydrodynamics: a conservation approach



Ana T. Silva

NINA
Norwegian Institute for Nature Research

Fish conservation and sustainability in rivers implies:

Interplay between fish (**endogenous factors:** motivation, physiology, fish life stage, species, size....) and the enviroment (**exogenous factors**: hydraulics, temperature, light, pH, oxygen, flow....)

Multidisciplinary approach :

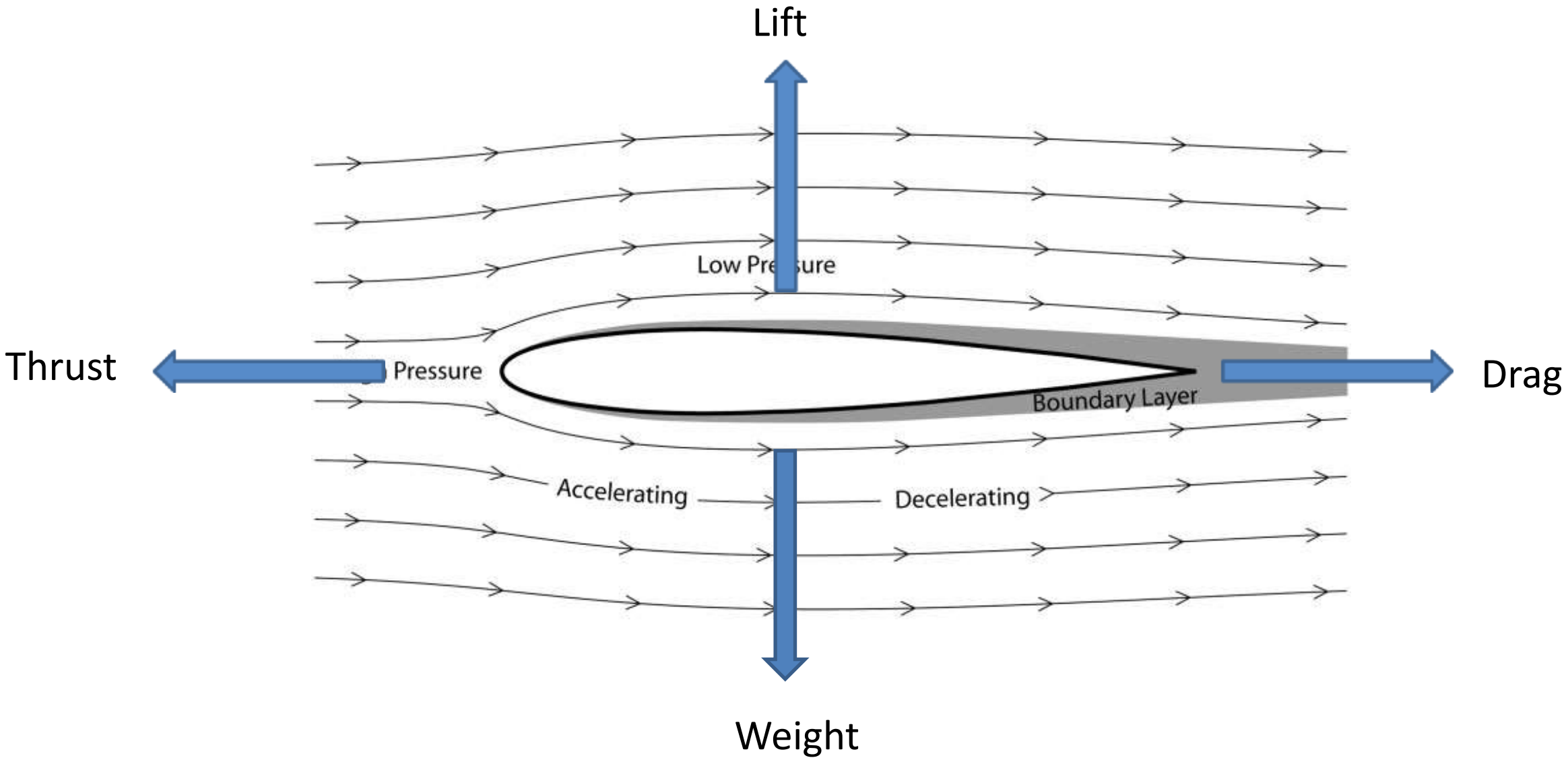
Biology, Physiology, Biomechanics, Hydraulics, Fish behaviour,

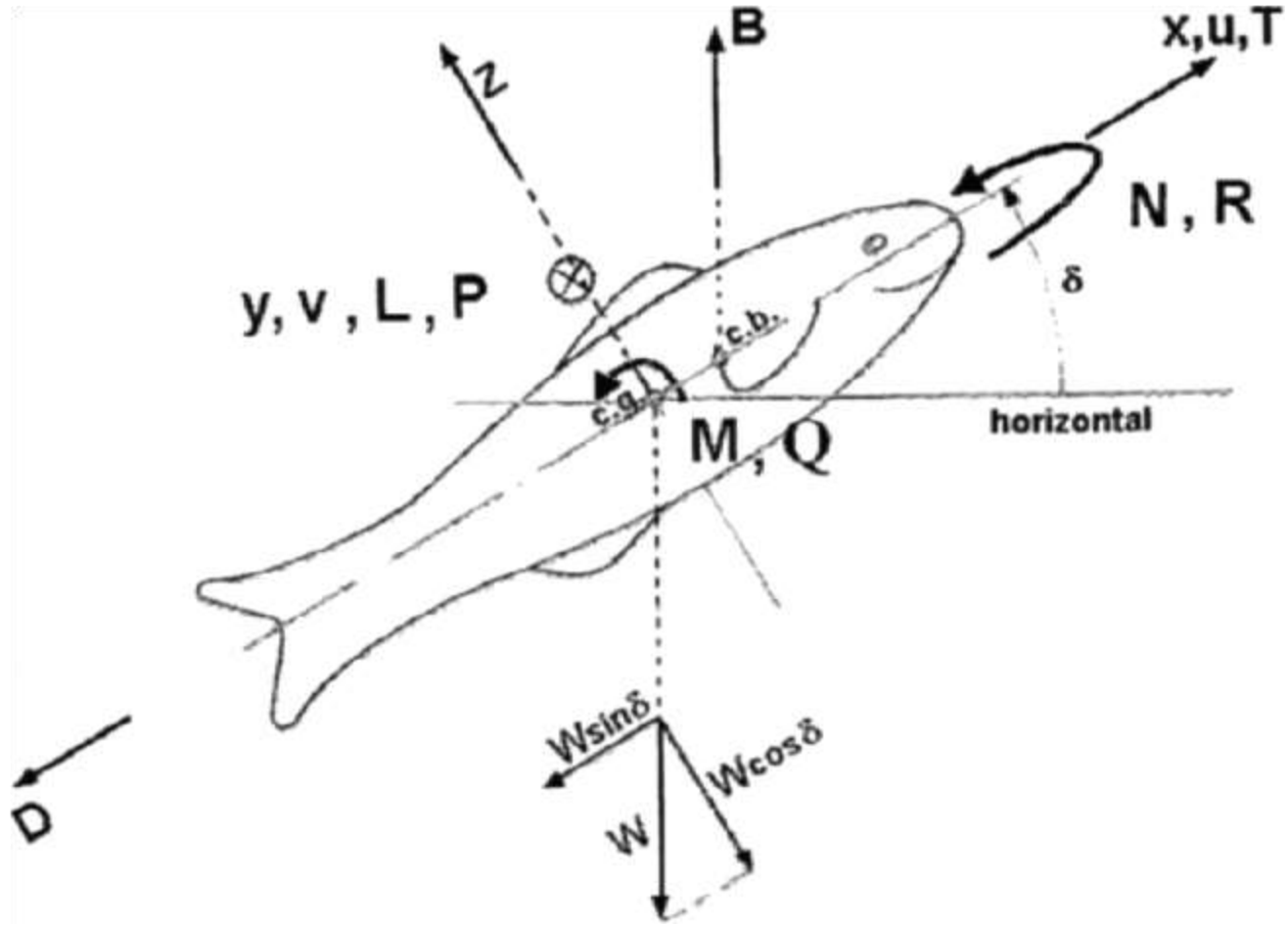
Neurobiology, Ecology,Hydrology, ... Economy, Sociology


Energy expenditure
Mike Baird

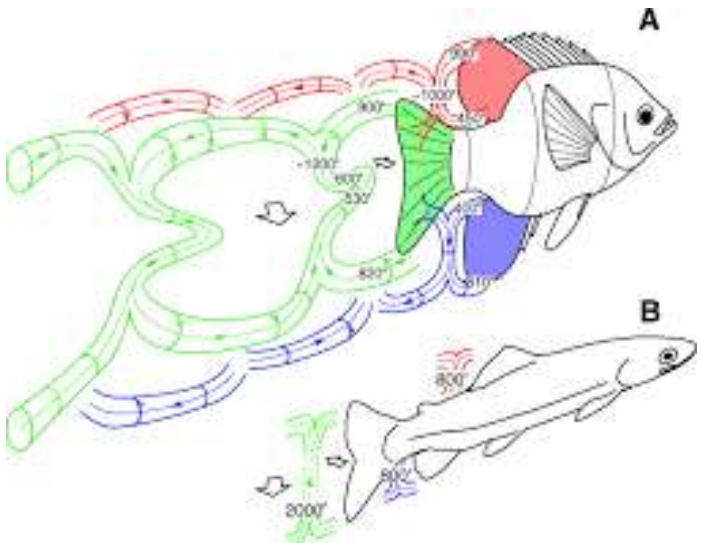
Energy expenditure associated to fish movement involves physiological and mechanical processes

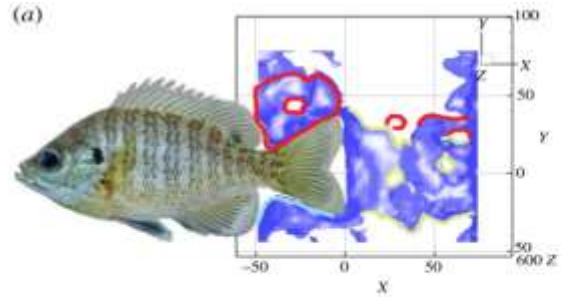
Energy expenditure associated to fish movement involves physiological and mechanical processes

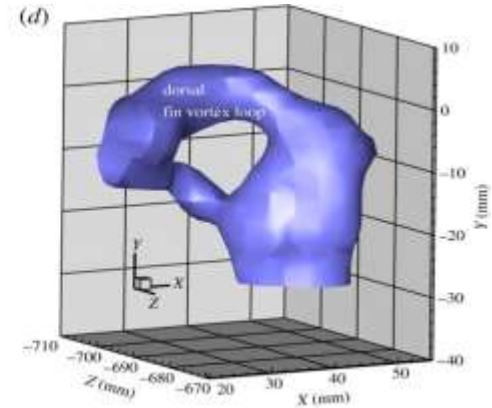

Lift
Thrust
Drag
Weight
Low Pressure
Pressure
Boundary Layer
Accelerating
Decelerating

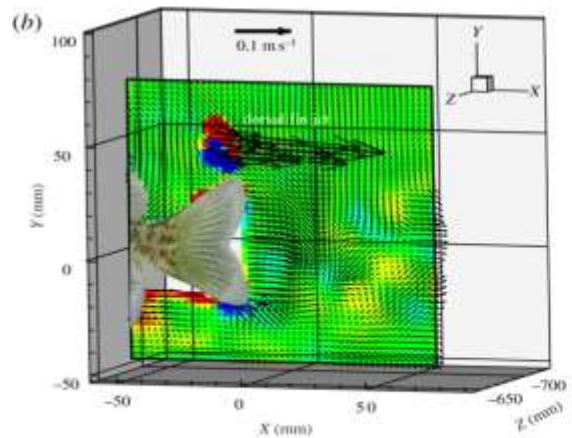

B
Z
x,u,T
N , R
y, v , L , P
c.b.
c.g.
δ
horizontal
M , Q
Wsinδ
Wcosδ
W
D

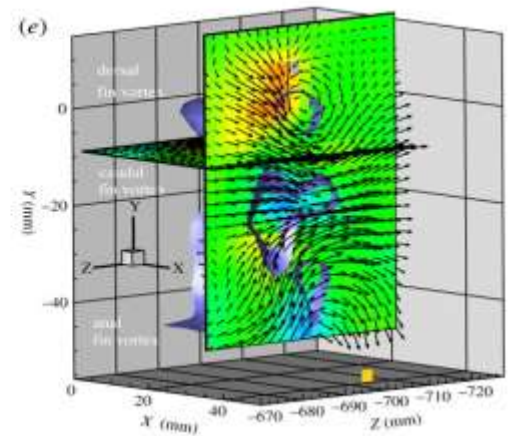
Fish use diferent appendices to swim and interact with flow hydrodynamics

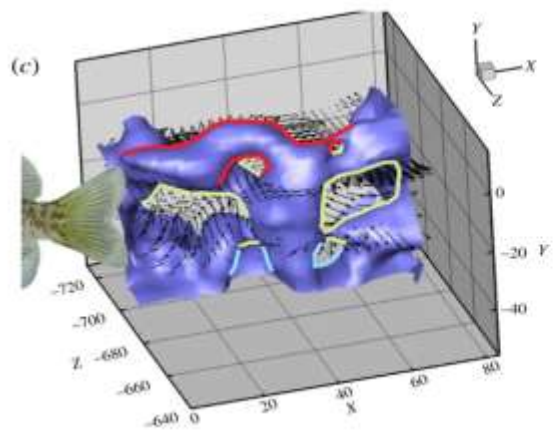


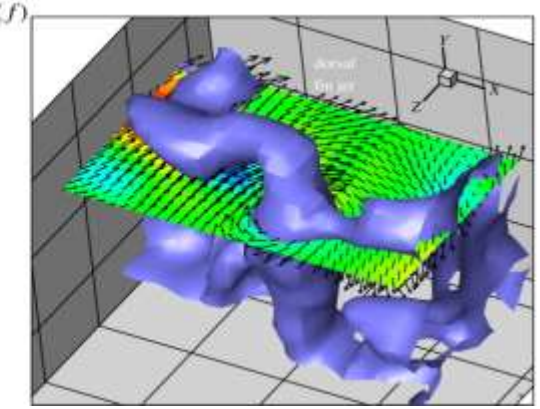




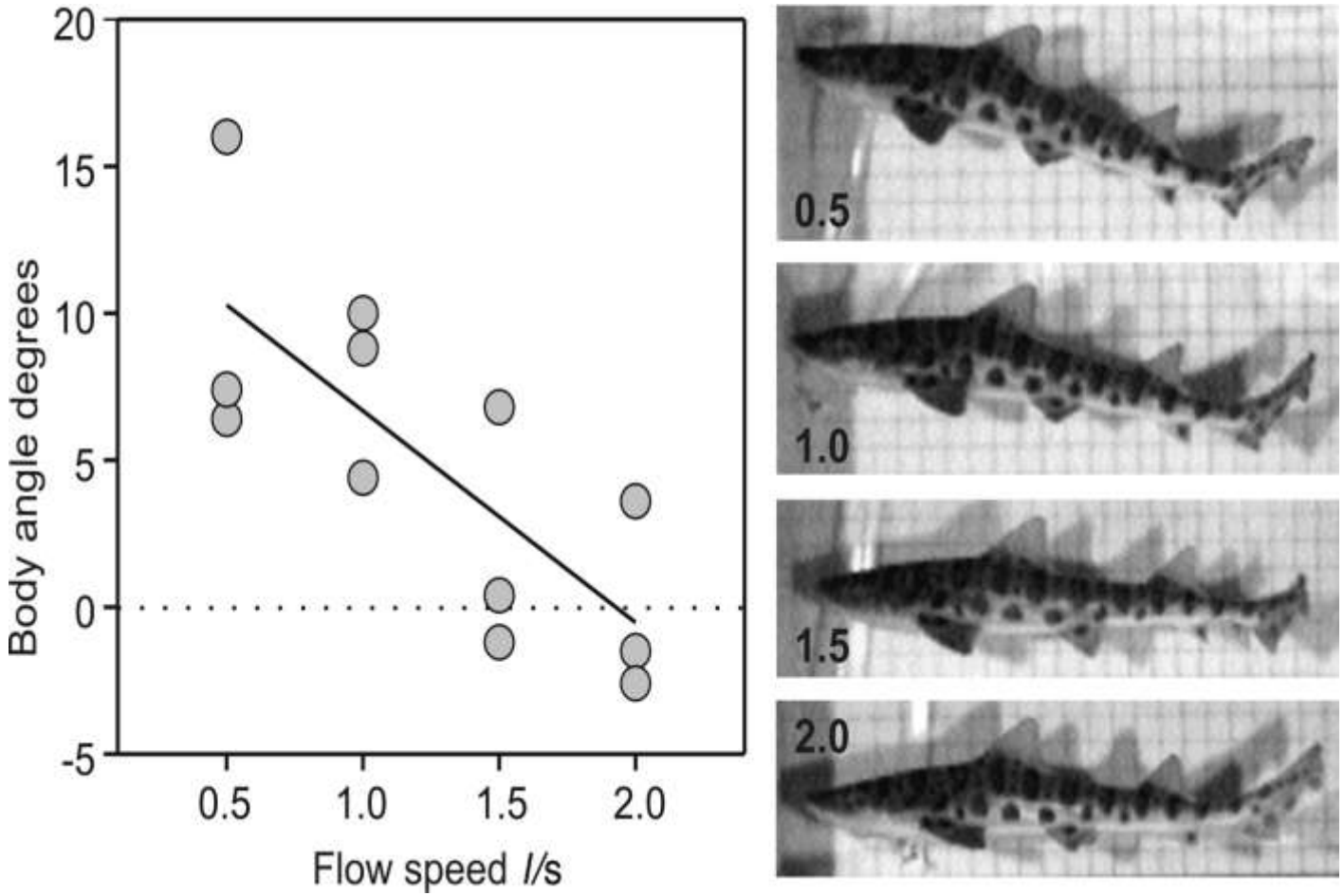


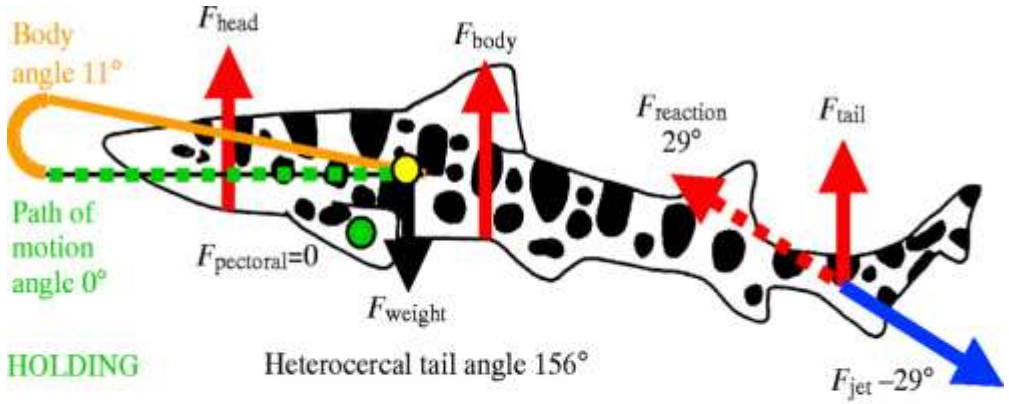


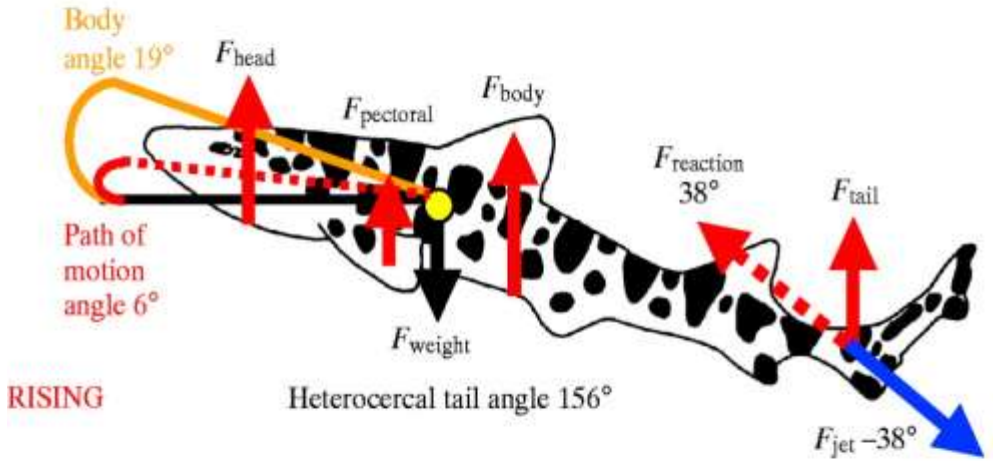


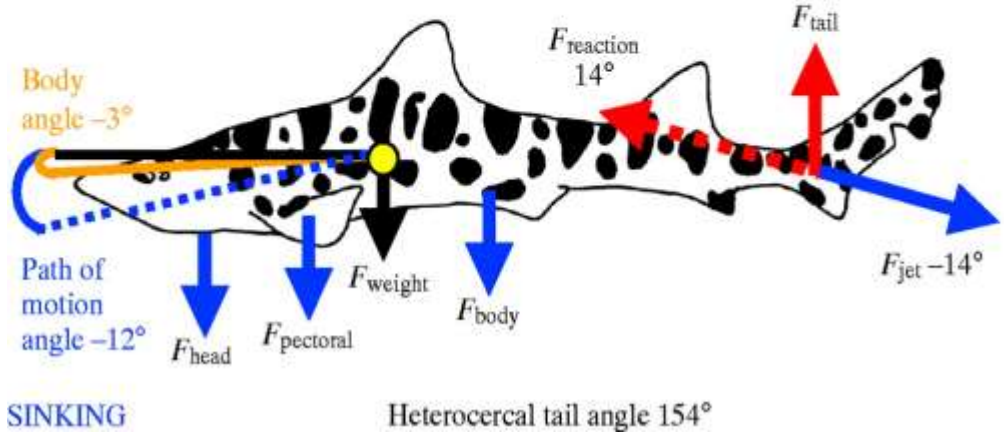


Fish use their body to interact with flow hydrodynamics

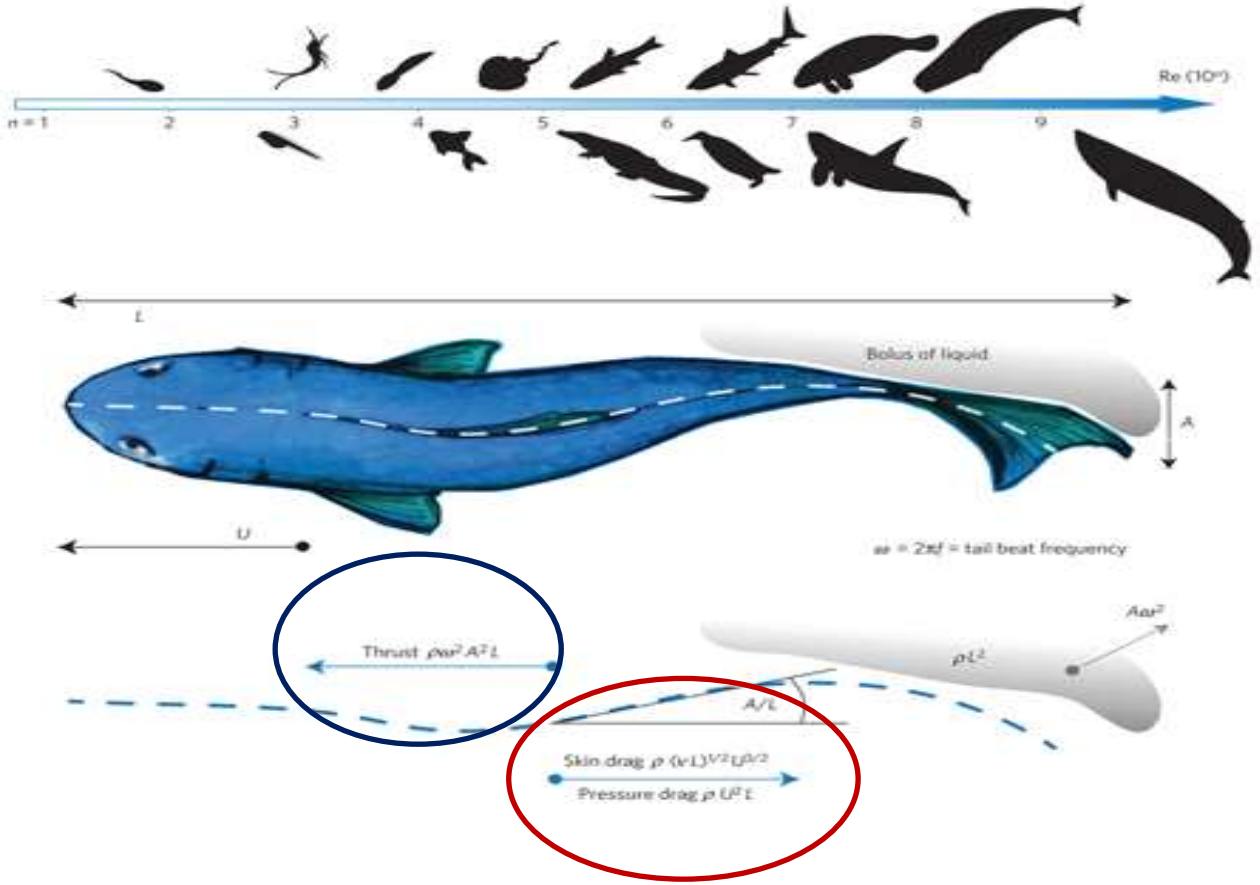


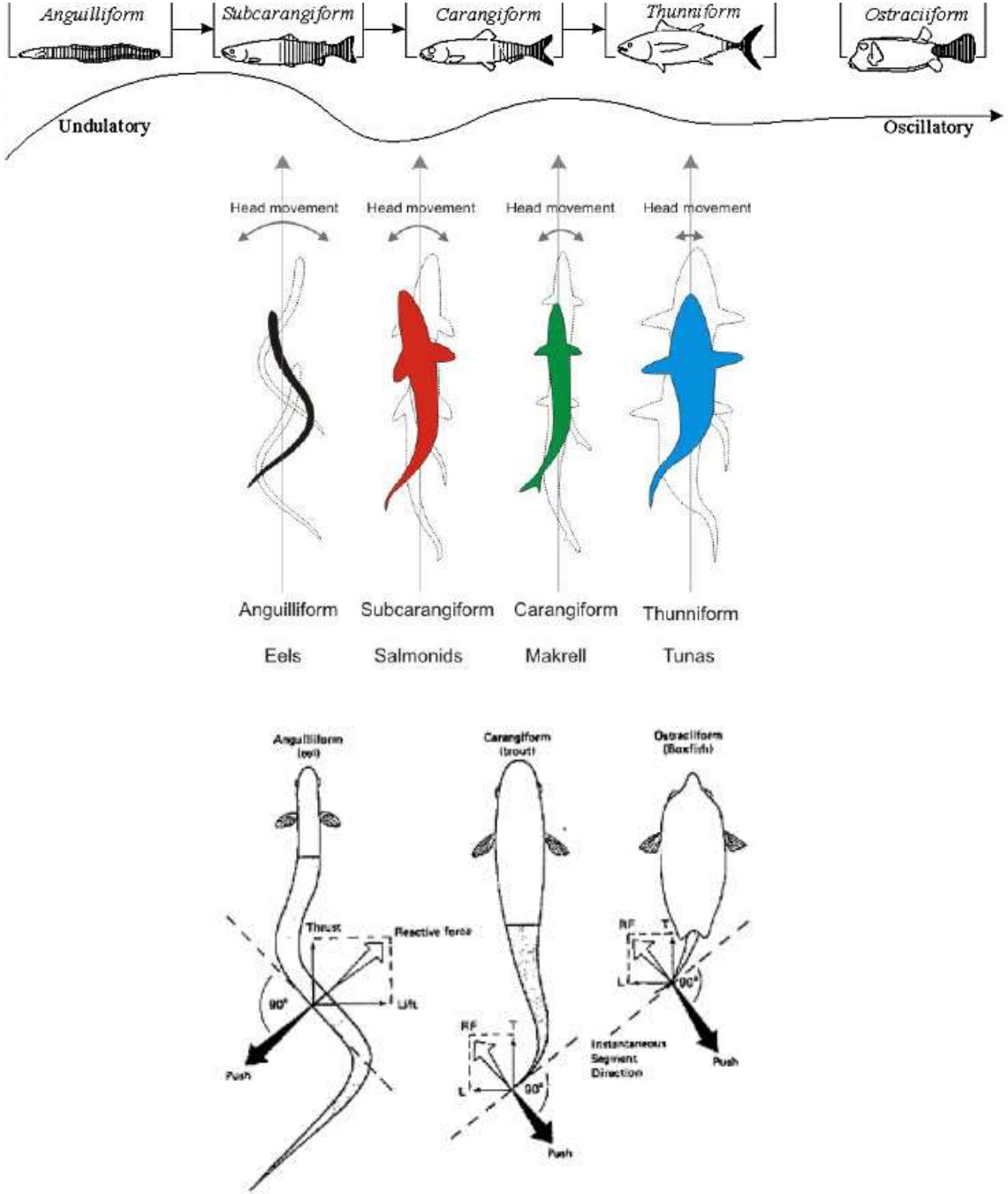




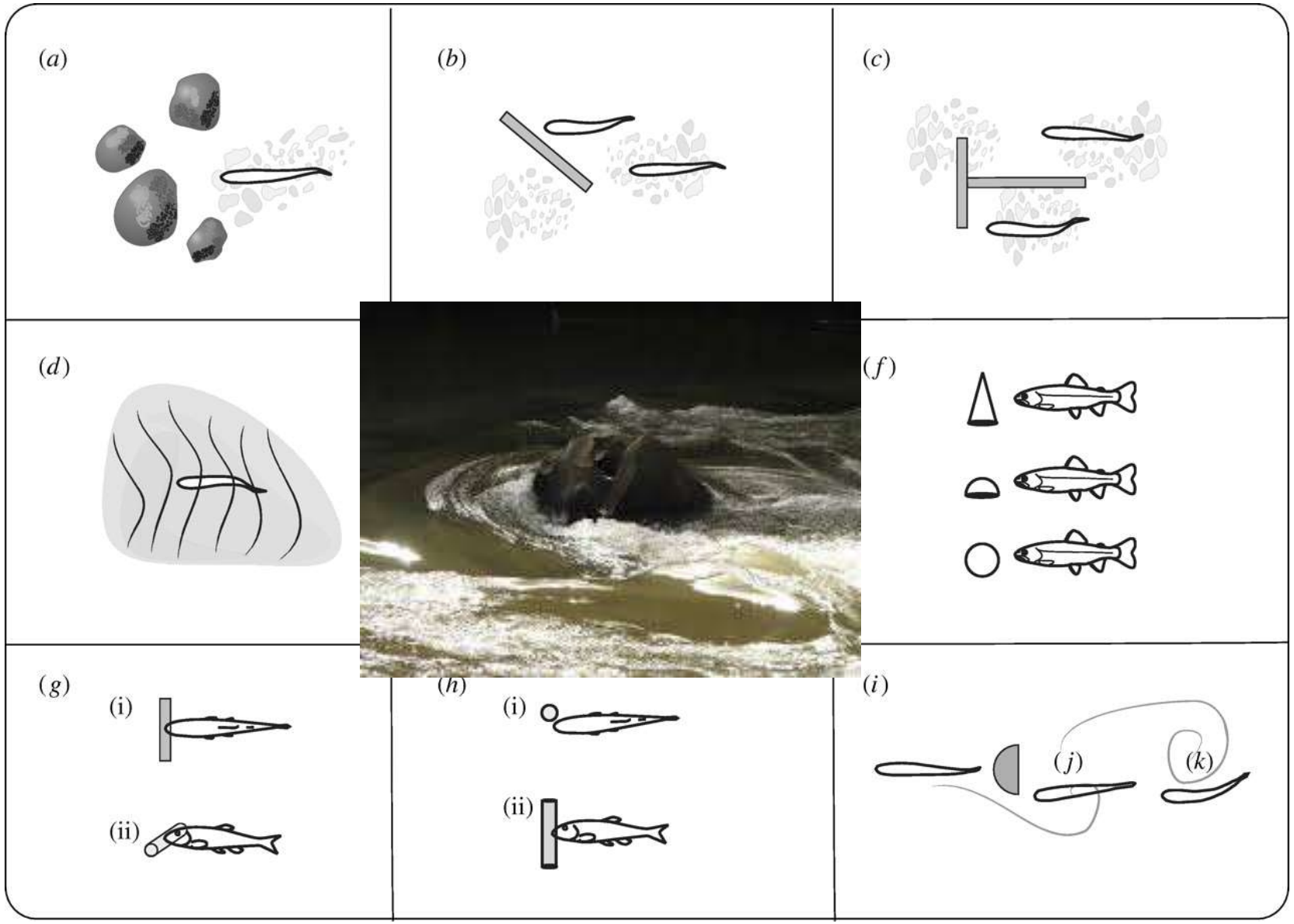


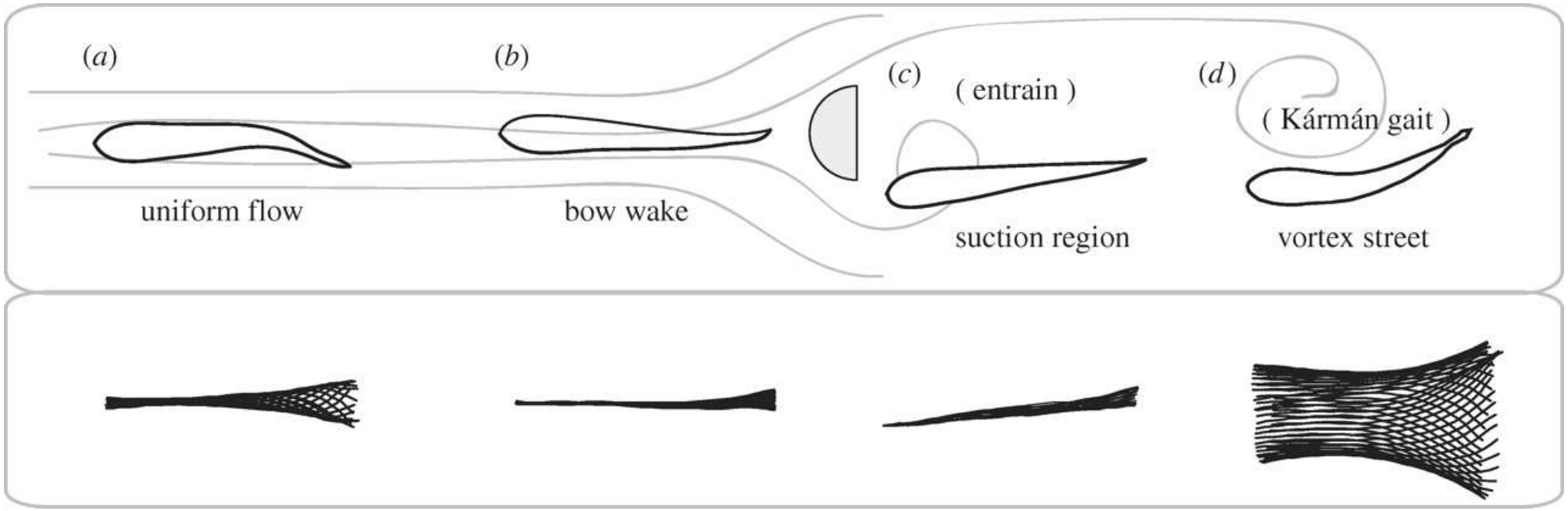
Wilga, C.D. and G.V. Lauder. 2000. *J. Exp. Biol* 203: 2261–2278

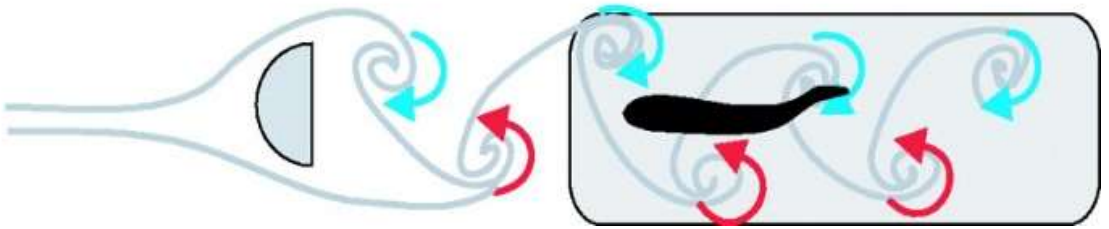

Re (10^n)
n = 1
2
3
4
5
6
7
8
9
L
Bolus of liquid
A
U
ω = 2πf = tail beat frequency
Thrust $\rho\omega^2 A^2 L$
$A\omega^2$
ρL^2
A/L
Skin drag $\rho\ (v\text{-}L)^{1/2} V^{1/2} L^{3/2}$
Pressure drag $\rho\ U^2 L$


Anguilliform
Subcarangiform
Carangiform
Thunniform
Ostraciiform
Undulatory
Oscillatory
Head movement
Head movement
Head movement
Head movement
Anguilliform
Subcarangiform
Carangiform
Thunniform
Eels
Salmonids
Makrell
Tunas
Anguilliform (eel)
Carangiform (trout)
Ostraciiform (Boxfish)
Thrust
Reactive force
Lift
90°
Push
RF
T
L
90°
Push
RF
T
L
90°
Instantaneous Segment Direction
Push

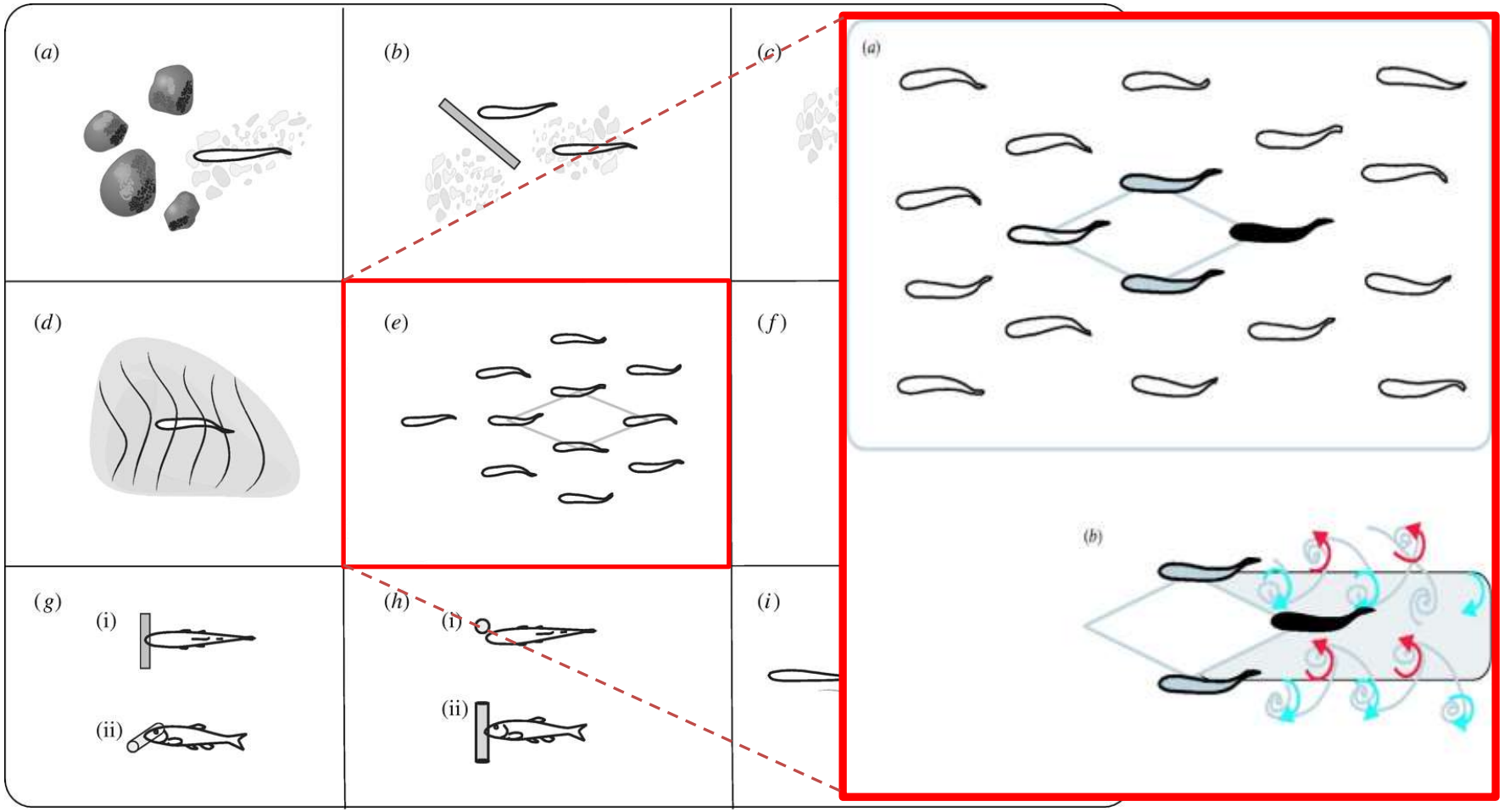
Interaction with fluid dynamics in Nature

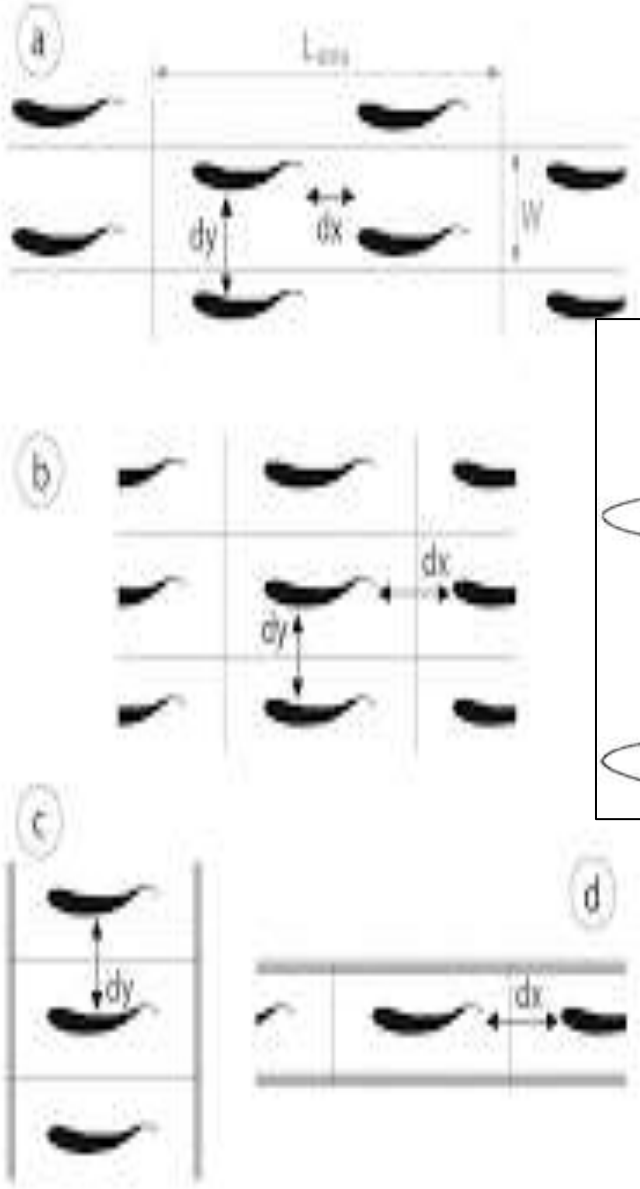


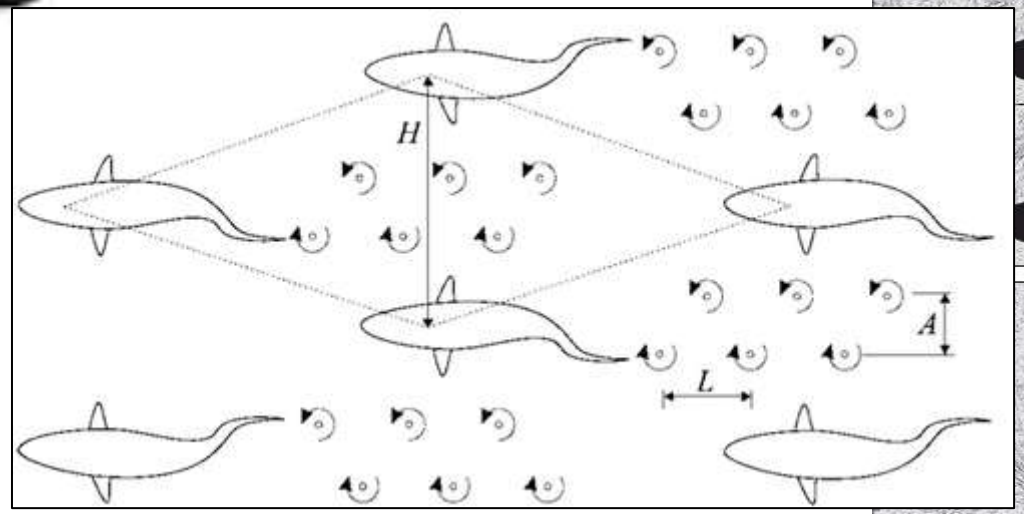

(a)
(b)
(c)
(entrain)
(d)
(Kármán gait)
uniform flow
bow wake
suction region
vortex street

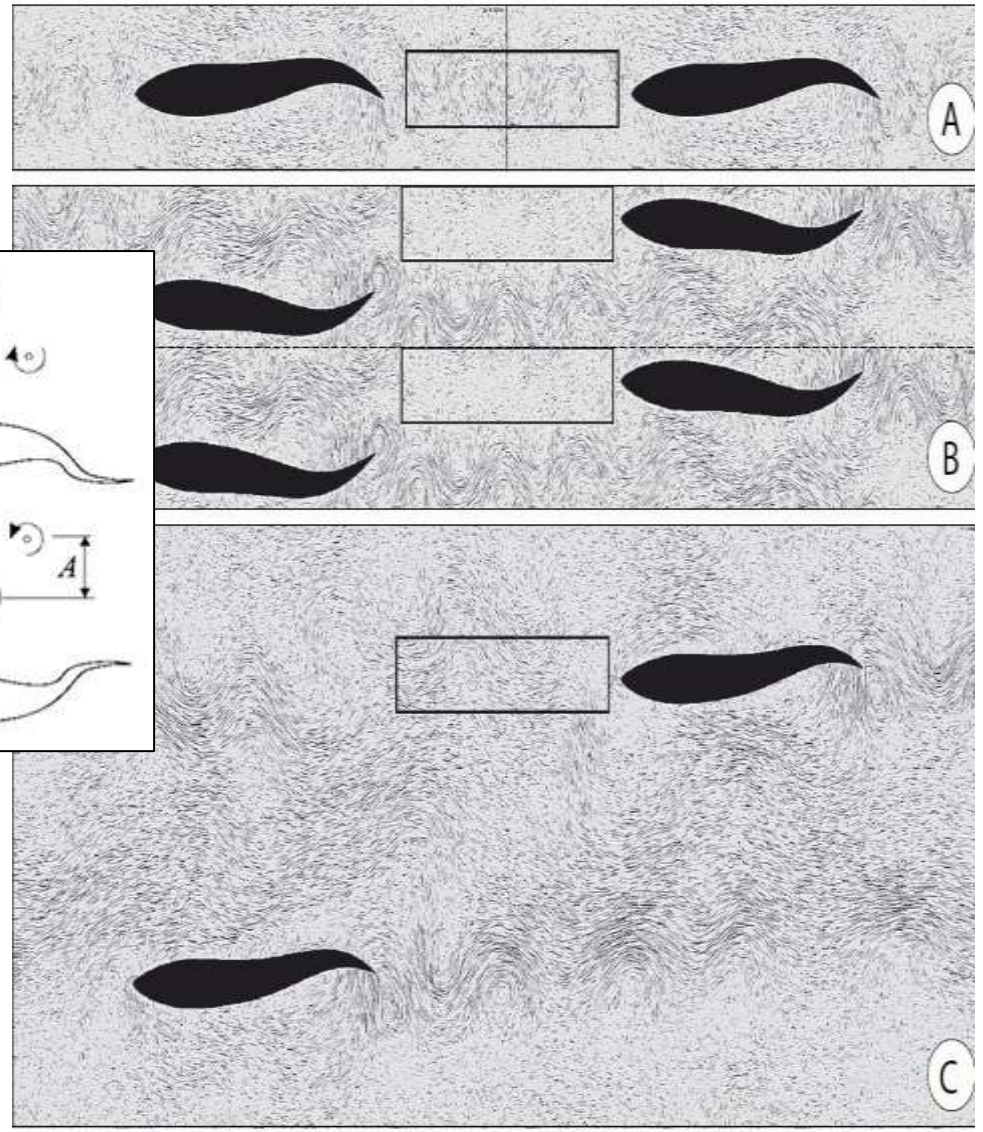


Interaction with fluid dynamics in Nature



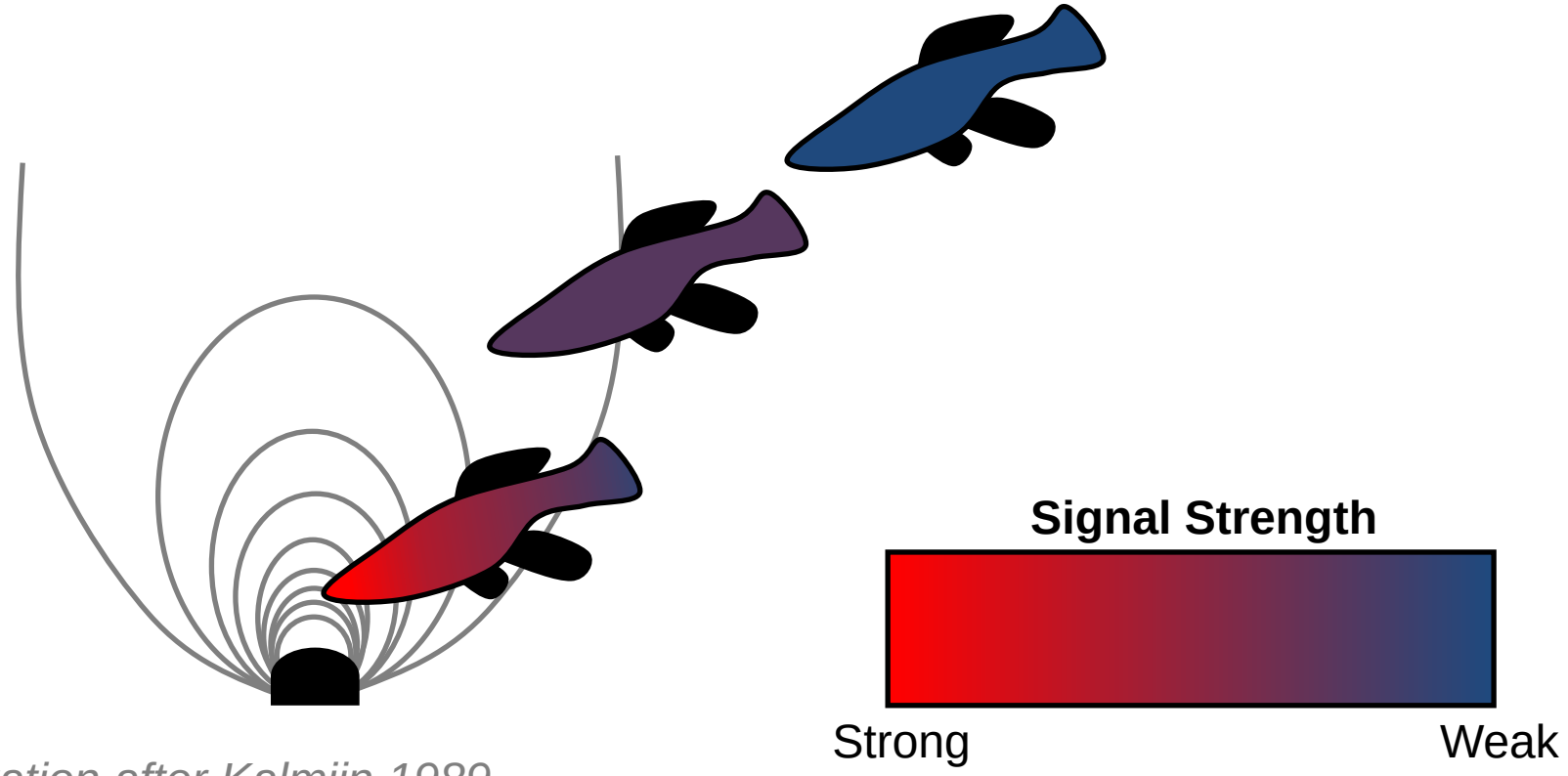






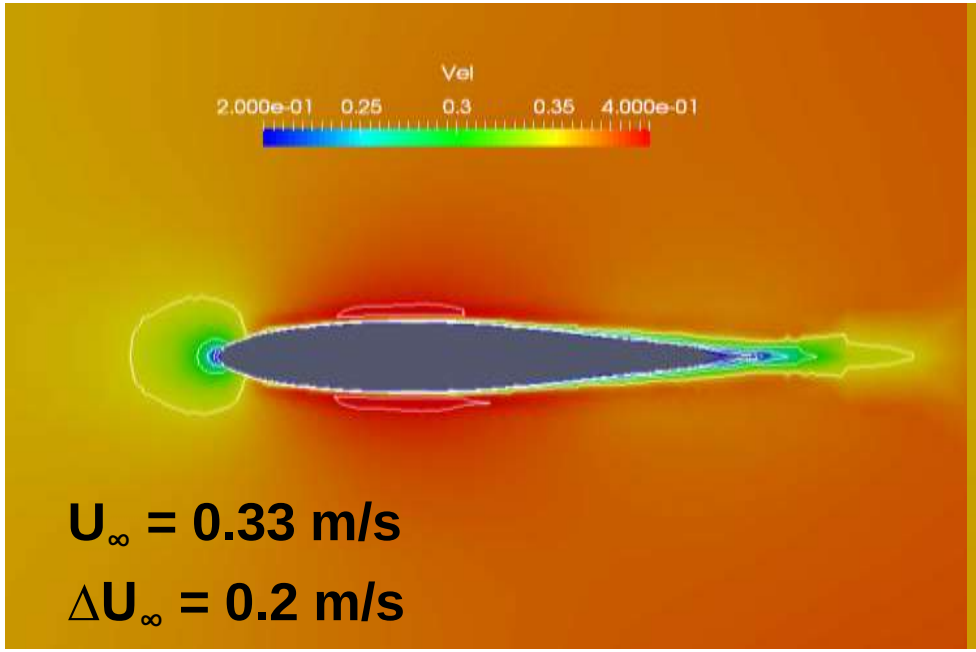
Hemelrijk et al. 2014 Fish and Fisheries

Hydrodynamic detection of **vibrational signals**‡, including sound consists of the **inner ear**, **superficial** and **canal neuromasts**



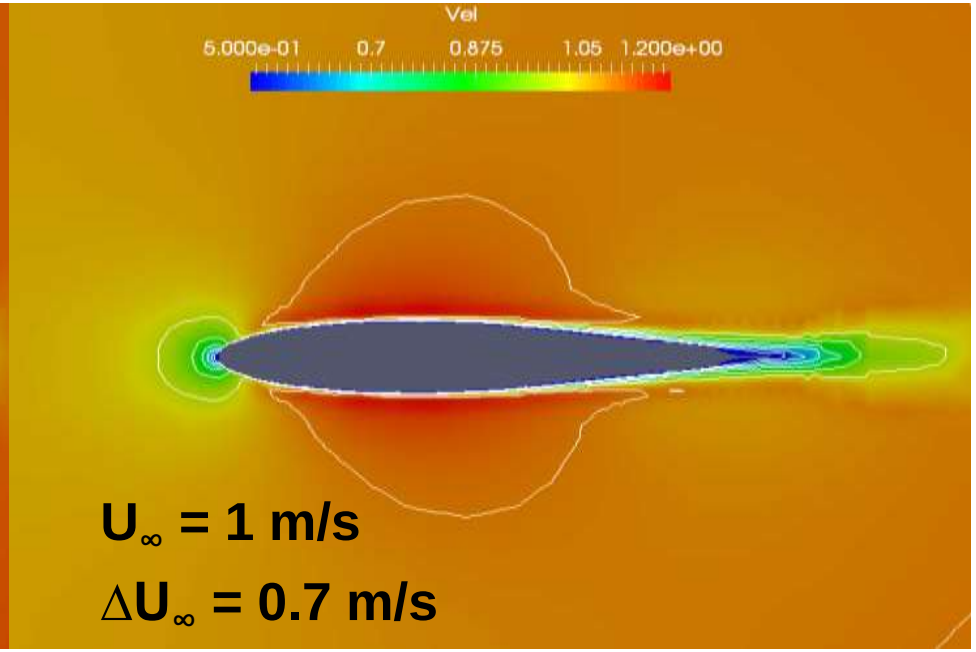
‡*Illustration after Kalmijn 1989*

A fish is not a point.



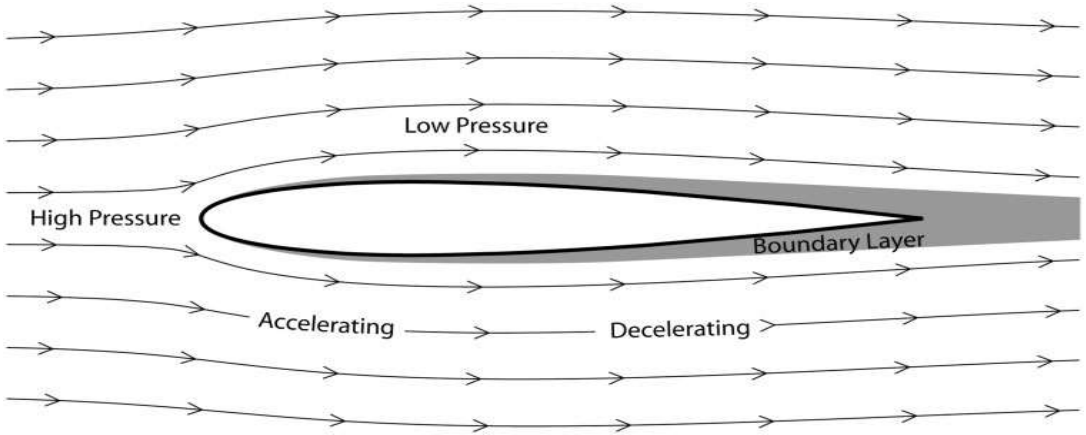
U_∞ = 0.33 m/s

ΔU_∞ = 0.2 m/s

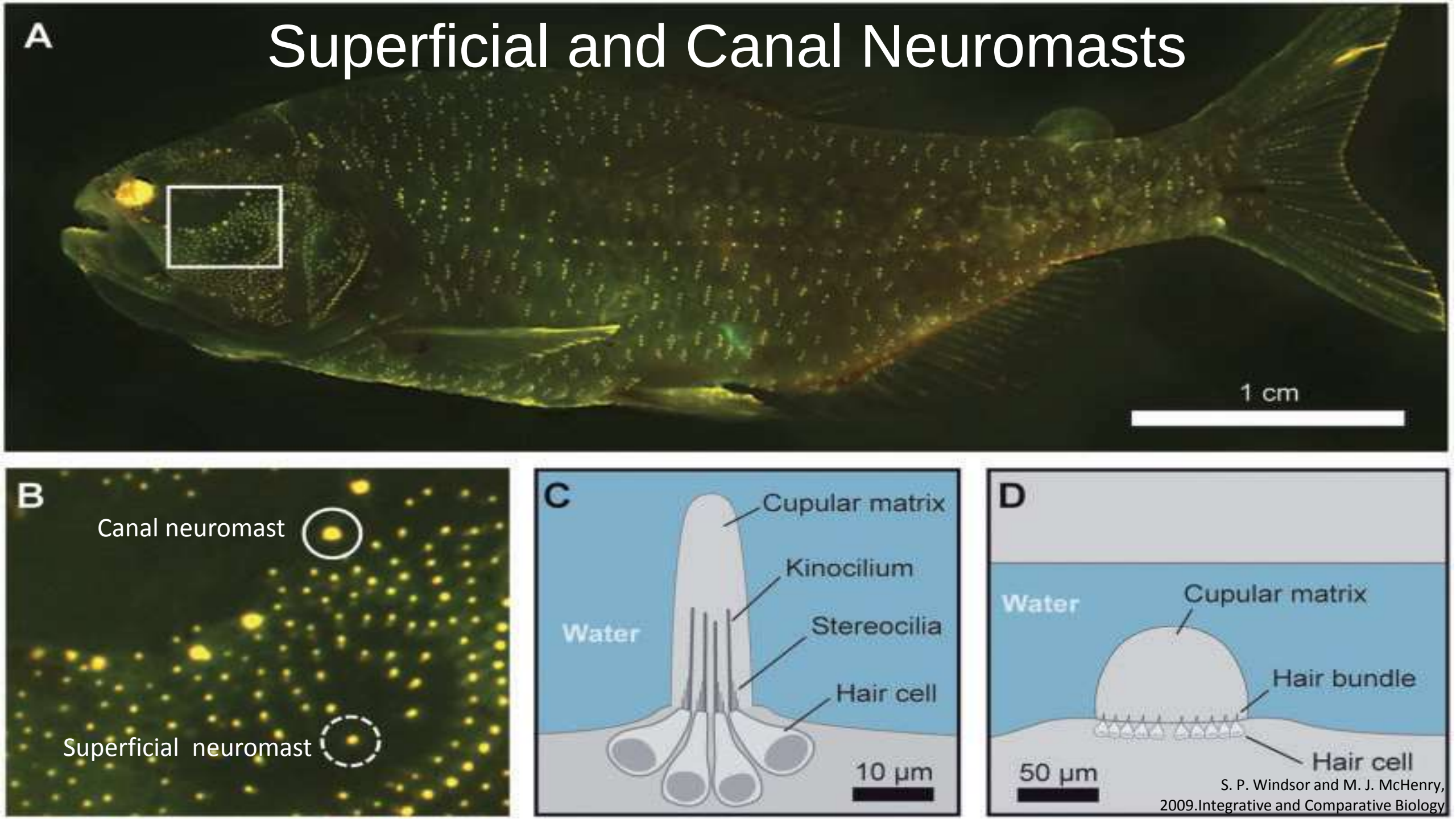


U_∞ = 1 m/s

ΔU_∞ = 0.7 m/s

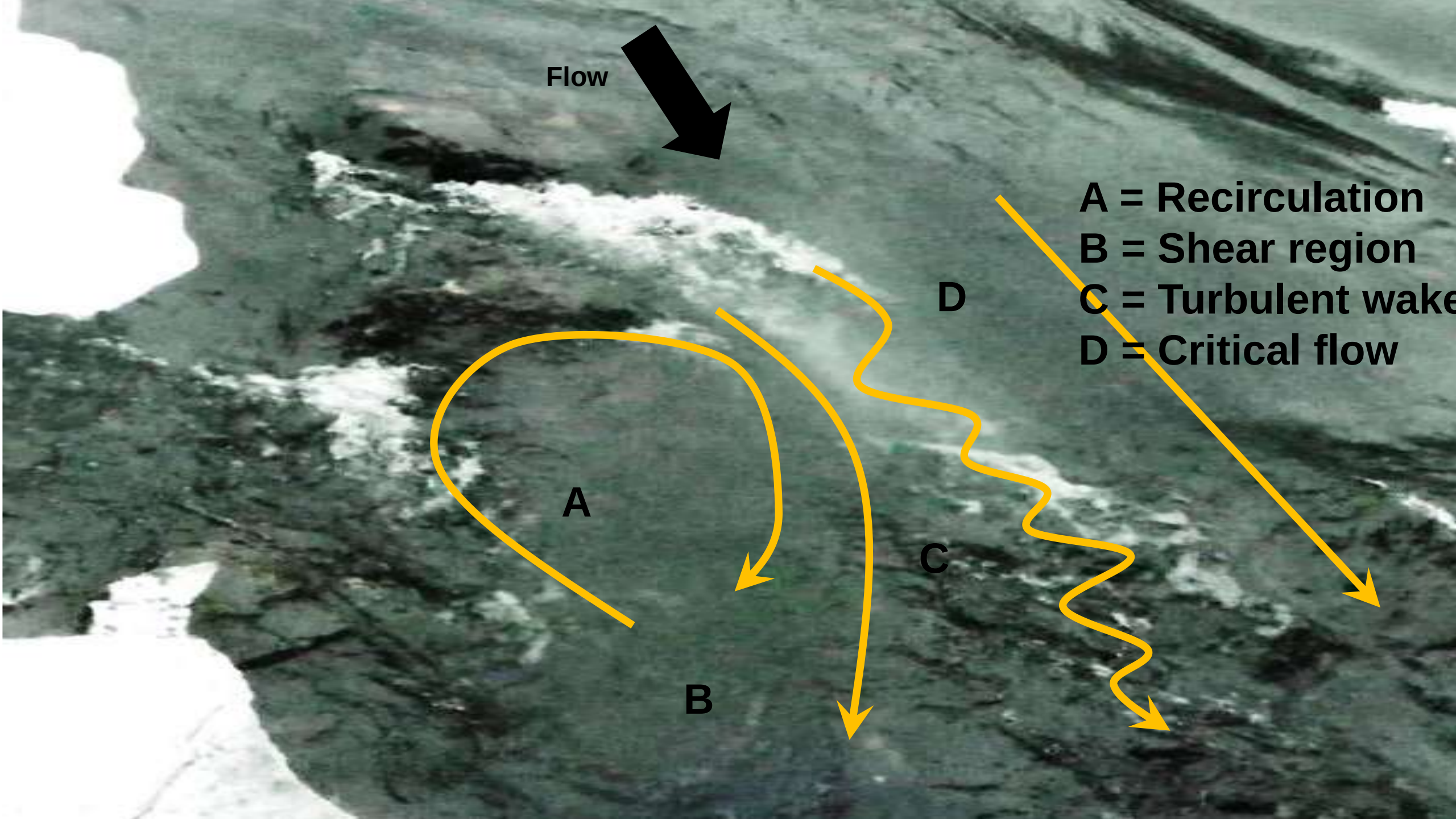


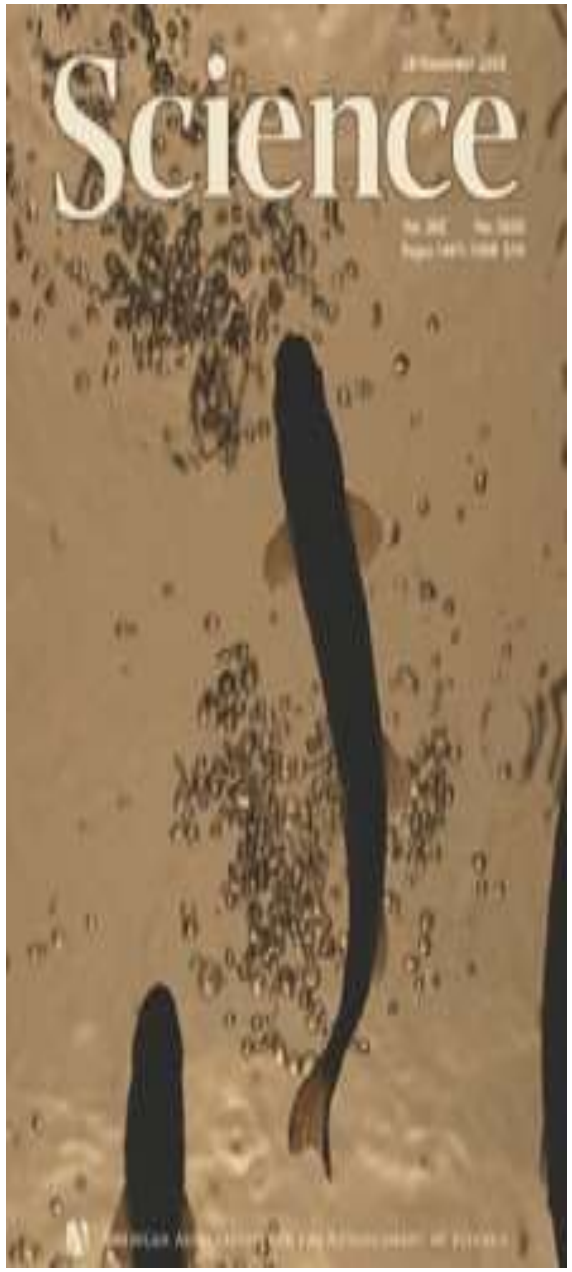
Superficial and Canal Neuromasts



S. P. Windsor and M. J. McHenry, 2009.Integrative and Comparative Biology

The turbulent world….


Flow
A = Recirculation
B = Shear region
C = Turbulent wake
D = Critical flow
D
A
C
B



Liao et al. 2003

Turbulence influence fish swimming behaviour

Turbulence intensity
Turbulence kinetic energy
Reynolds shear stress
Eddies size and vorticity

Shear stress strongly impacts fish behaviour

Small fish

Large fish

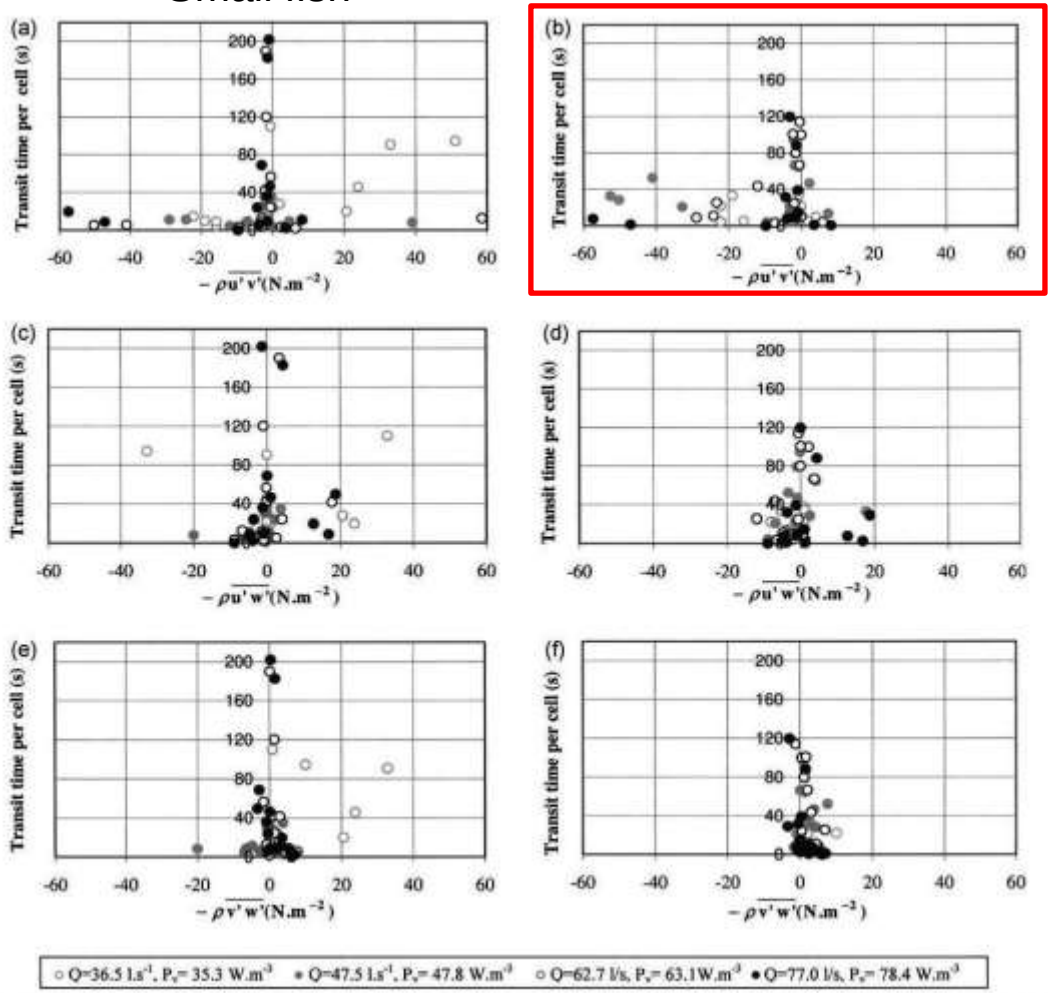
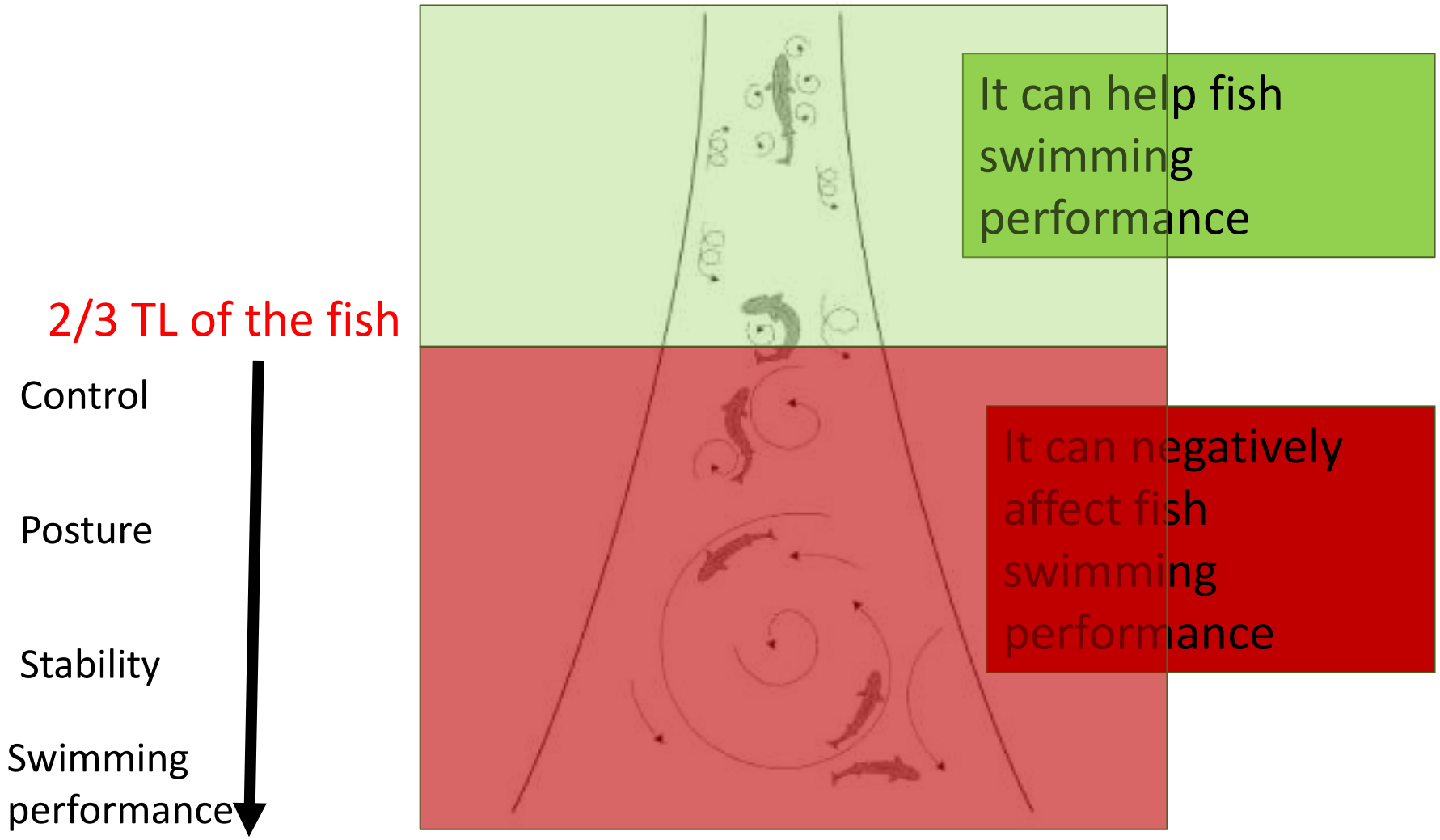


Figure 9. Distribution of fish transit time per cell(s) versus Reynolds shear stress ($-\rho\overline{u'v'}$, $-\rho\overline{u'w'}$ and $-\rho\overline{v'w'}$) in each cell at z = 0.25 h_{ac}: (a), (c), (e) respectively, for small adults (15< TL <25 cm) and (b), (d), (f) respectively, for large adults (25≤ TL <35 cm)

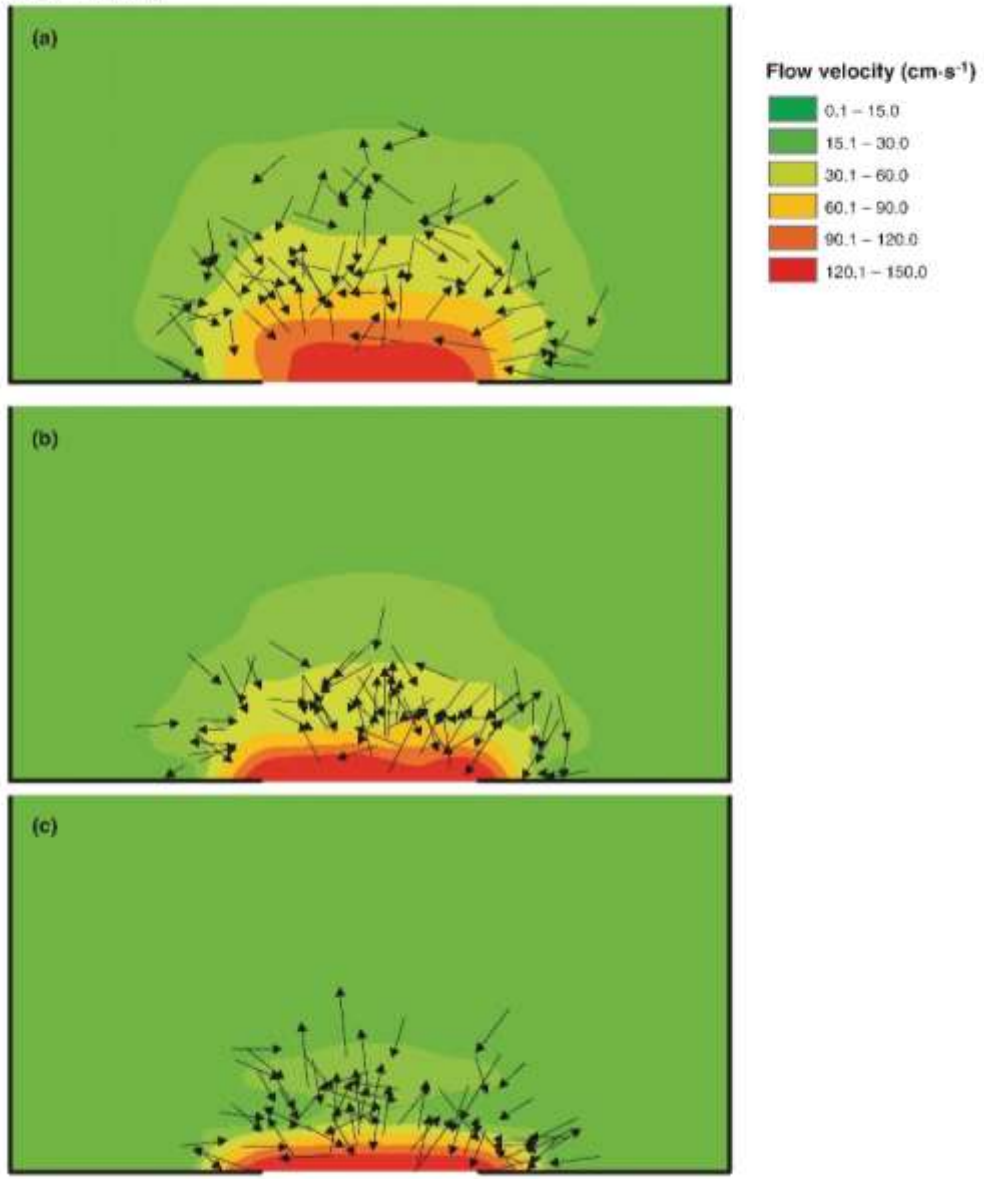
Silva et al.,2011

Eddies can affect or help fish swimming



Odeh et al, 2002

Fig. 2. Maps of velocity (V) in the test arena of the experimental flume under (a) high-, (b) medium-, and (c) low-flow conditions. The positions at which smolt displayed typical avoidance response to the accelerating flow are indicated by arrows. The arrowhead symbolizes the position of the fish head.

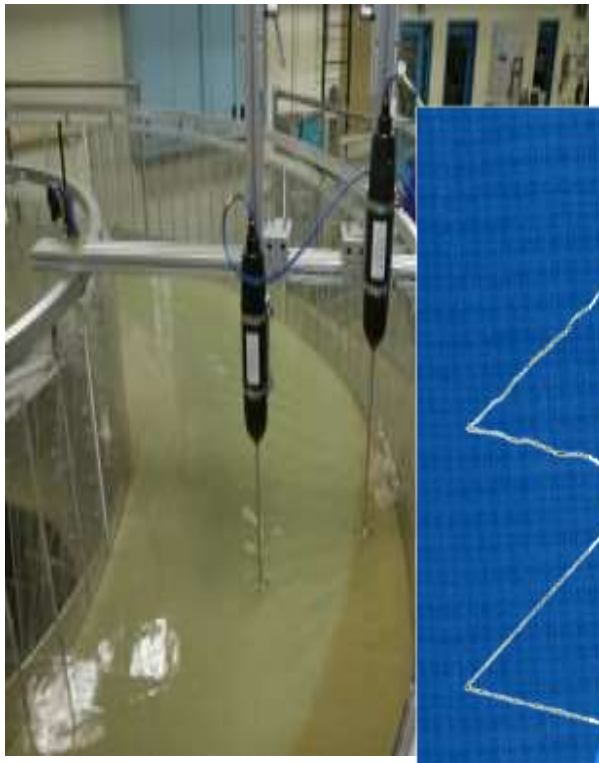


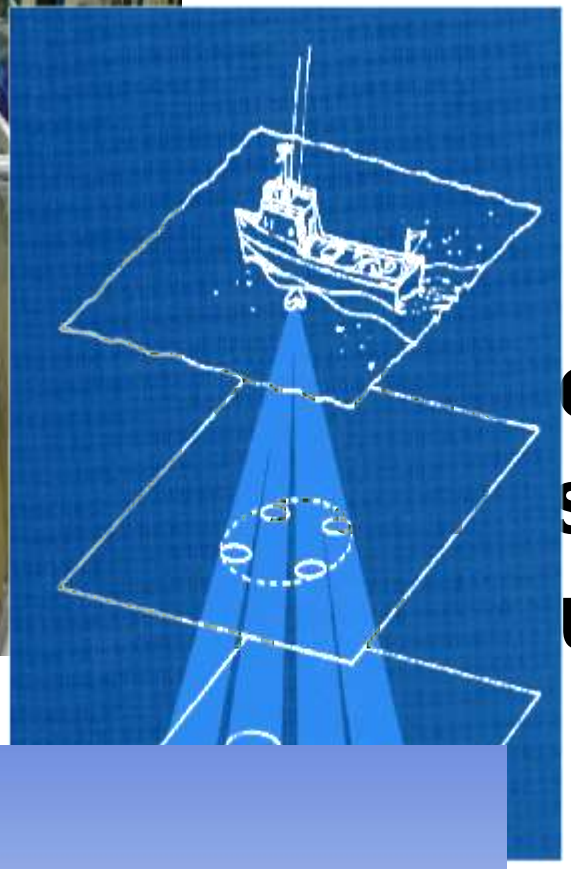
Avoidance of Acceleration

But acceleration can also attract fish!

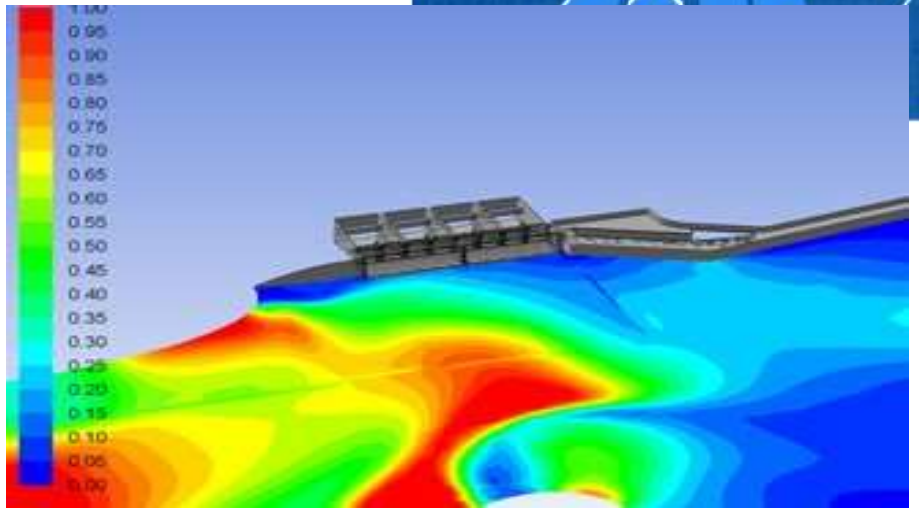
Enders et al.,2009

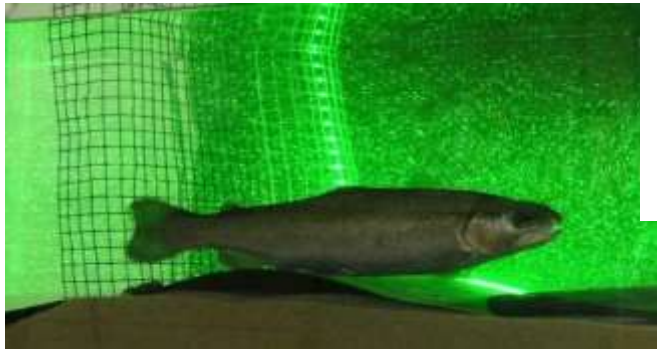

Which route?
What to follow?

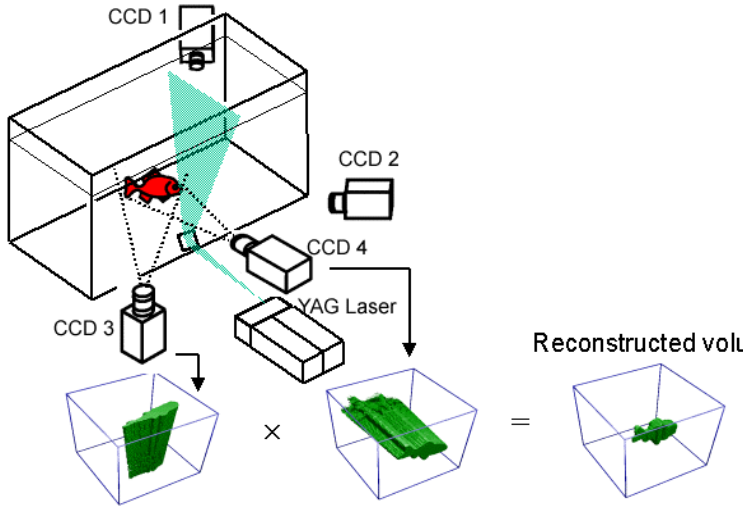





Acoustic Tag
Radio Tag
PIT Tag
Acoustic Tags






CCD 1
CCD 2
CCD 4
YAG Laser
CCD 3
Reconstructed volu

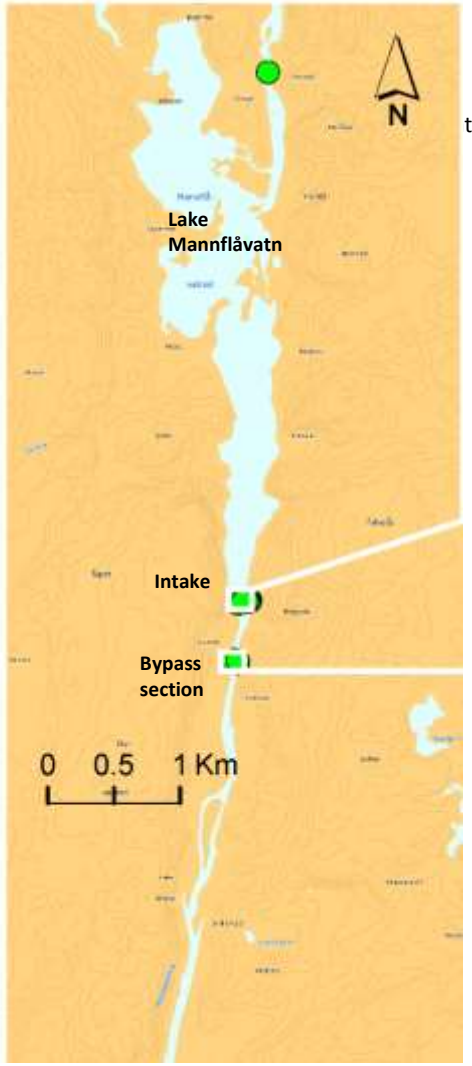
SWIMMING BEHAVIOUR v.s HYDRAULICS

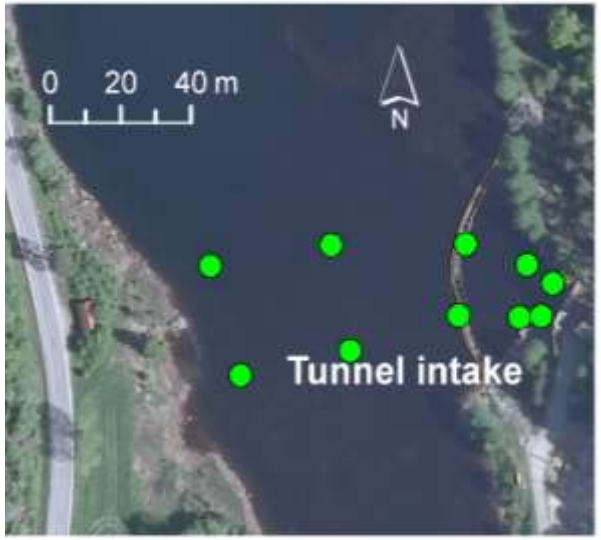
CASE STUDY: MANDAL RIVER

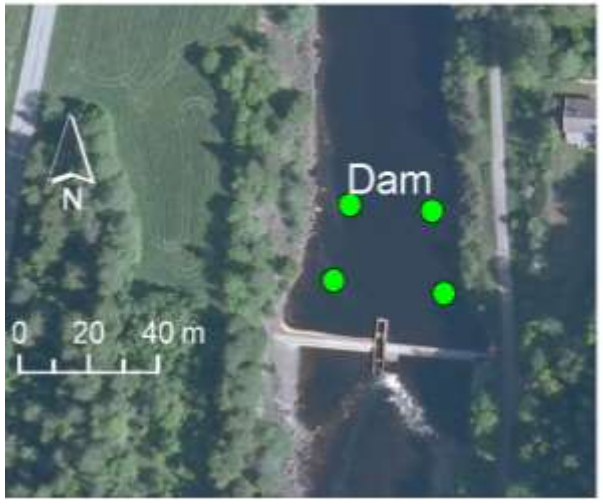
(SAFEPASS - Safe and efficient two-way migration for salmonids and European eel past hydropower structures)

NINA
Norwegian Institute for Nature Research

2D and 3D Telemetry







-200 kHz acoustic telemetry hydrophones (Lotek).
- Small tags (15x6.5 mm), burst interval of 5 s last for 45 days.
- 99 tagged smolts

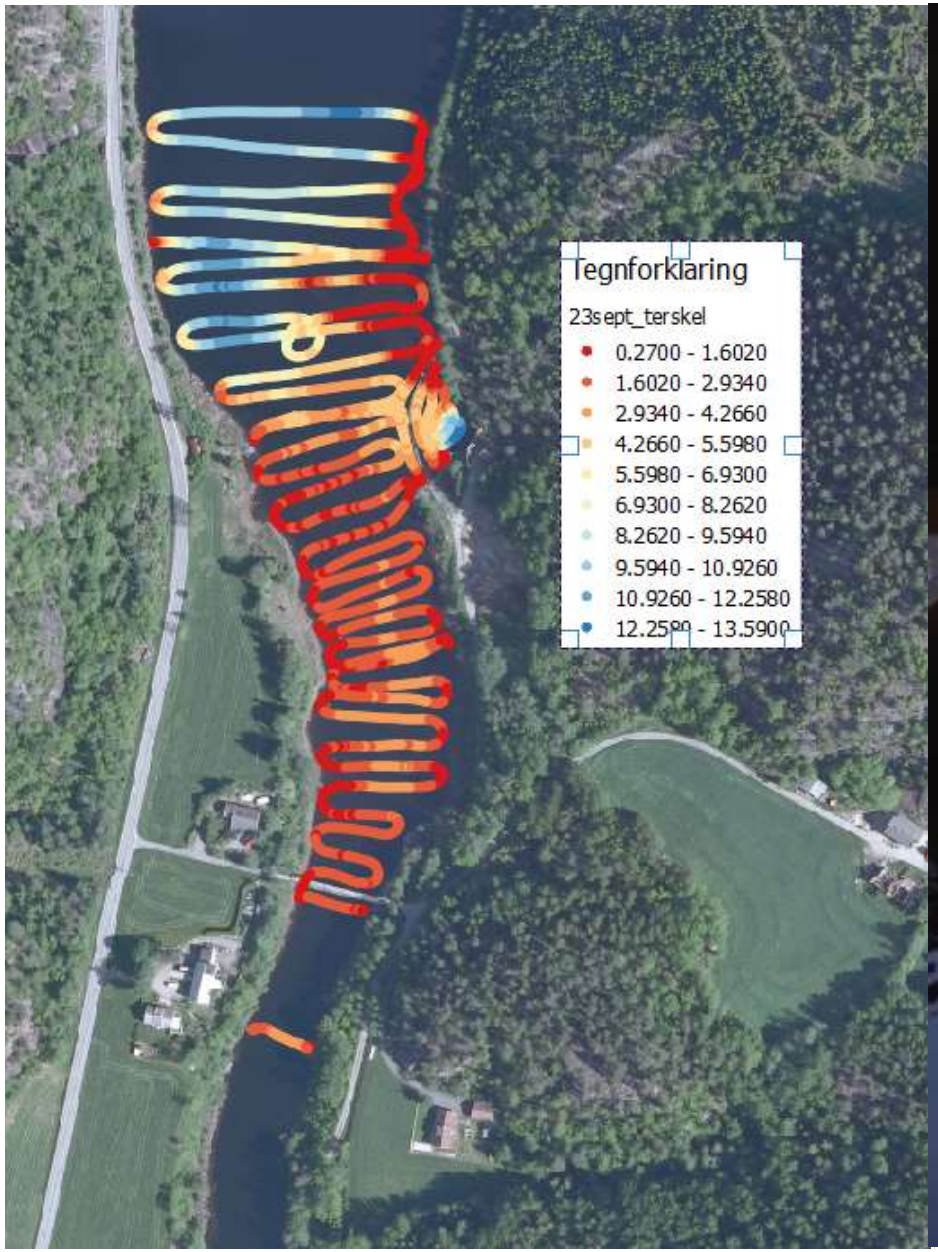
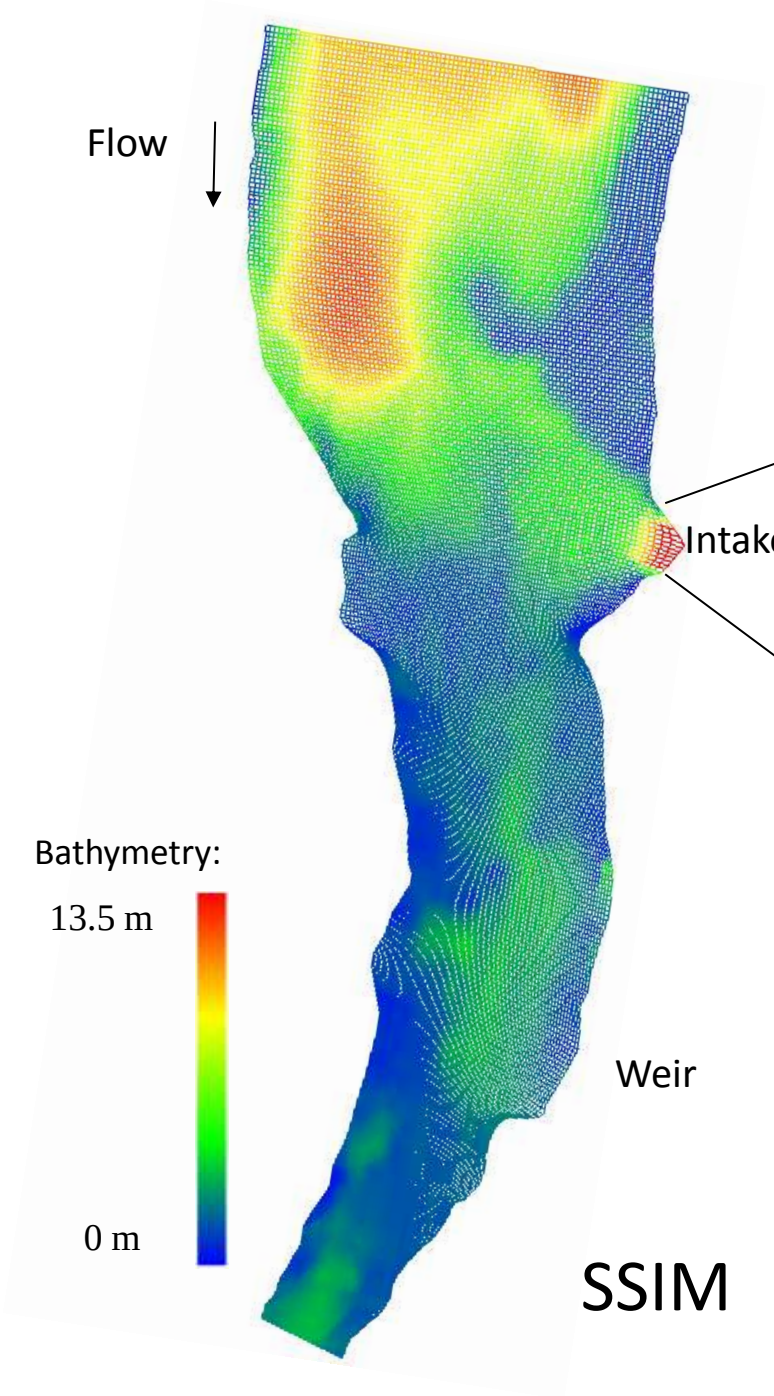
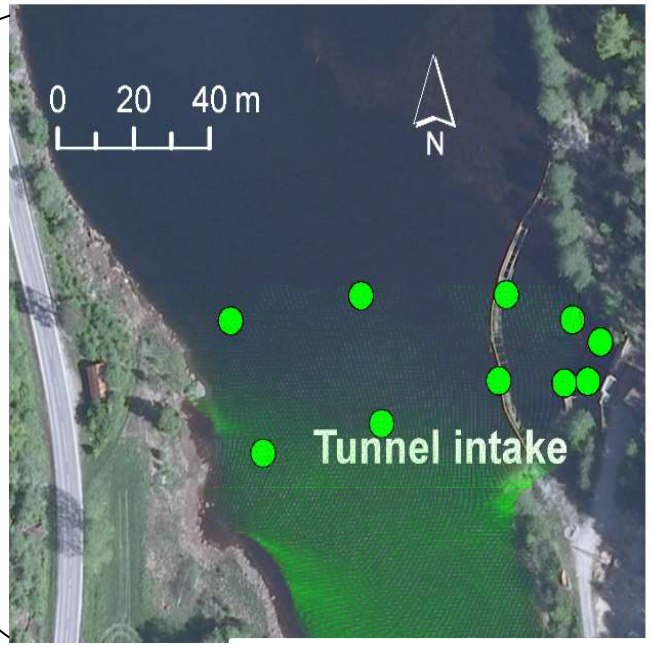


Photo: Hans-Petter F.

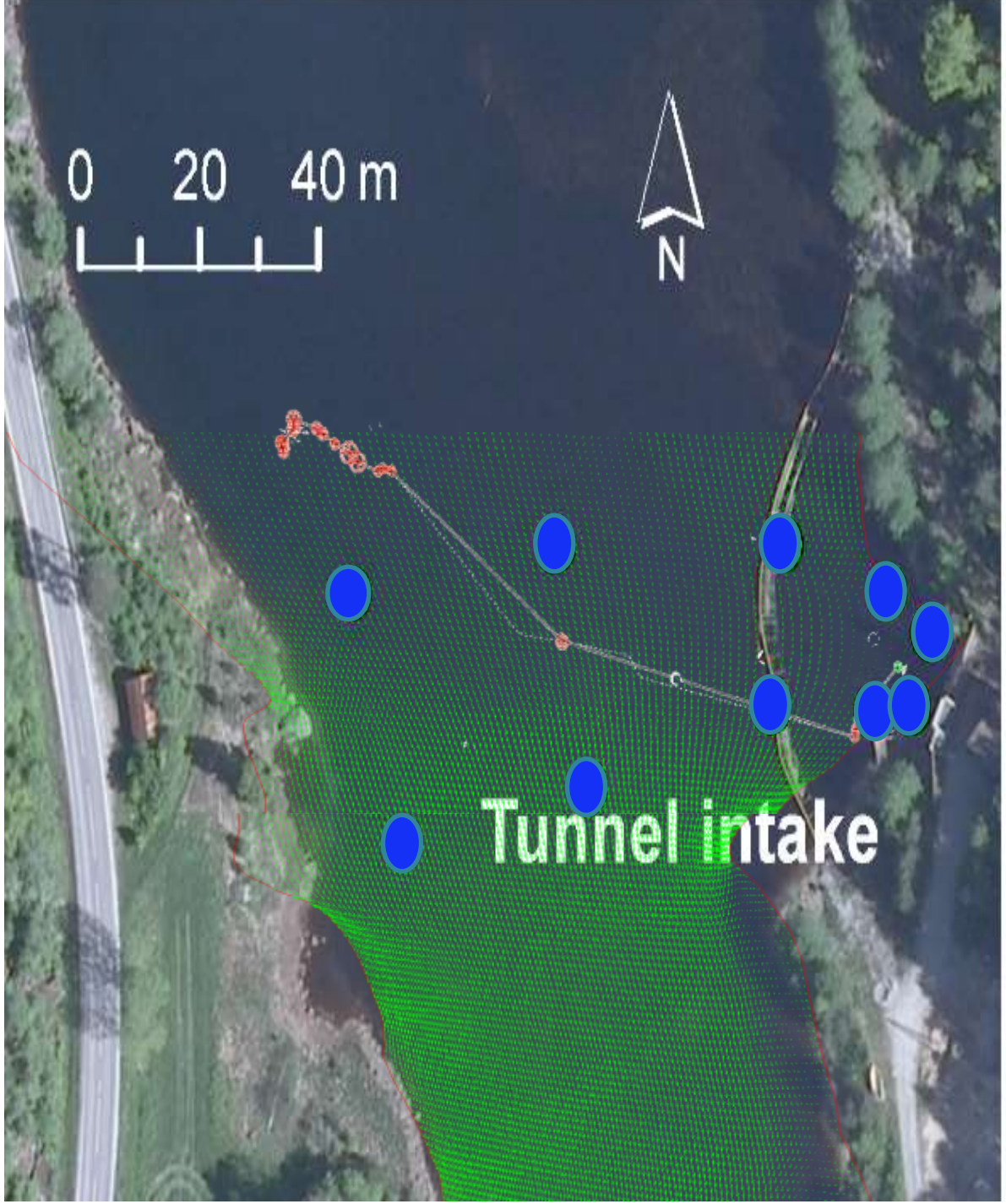
Hydraulics :

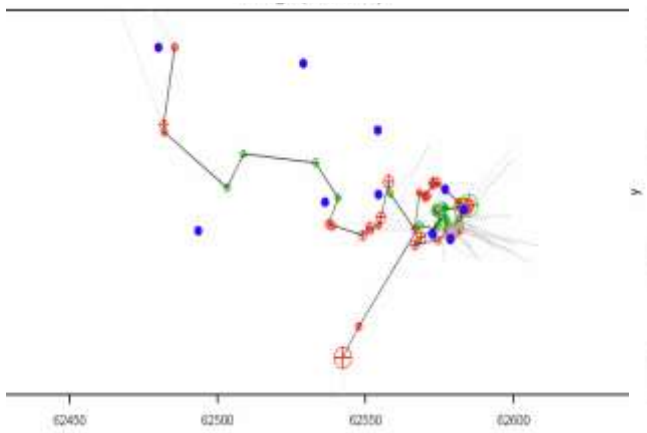


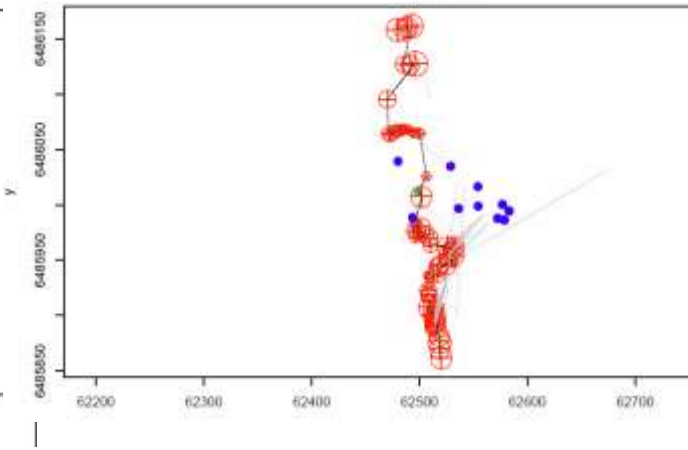
SSIM

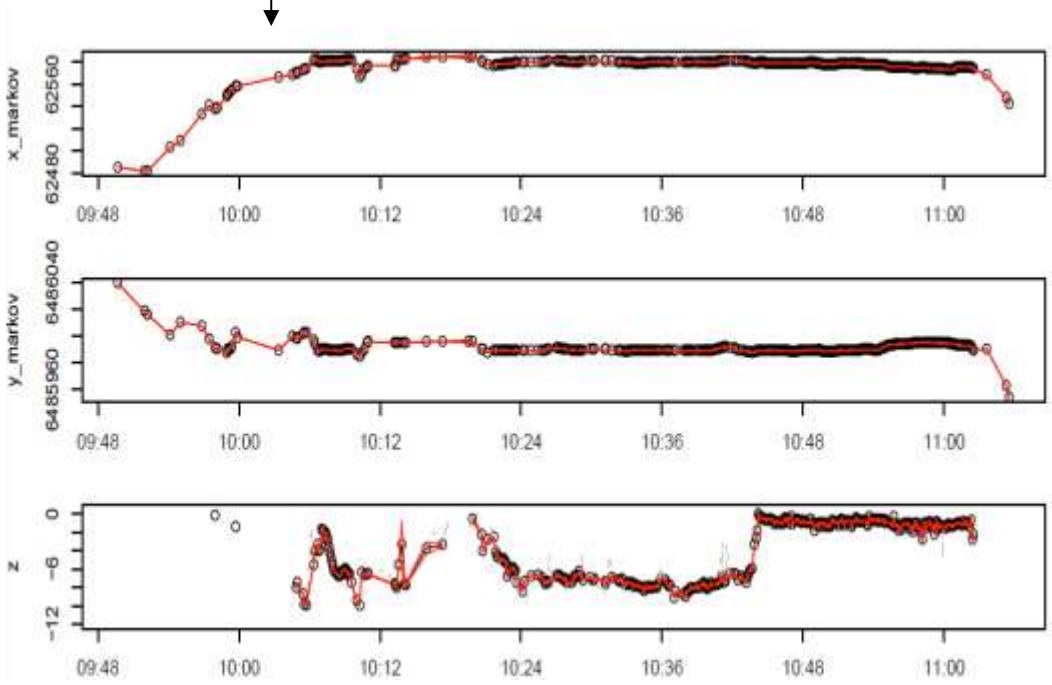


Migratory route of fish









Take home message

An interdisciplinary approach that combines disciplines like fish biology and hydraulics is needed to achieve:

- Fish conservation in a ecological, evolutionary, and socioeconomic sustainability

- Animal welfare and fisheries

- Environmentally engineering solutions.

Thank you !