Fish habitats, swimming and turbulence

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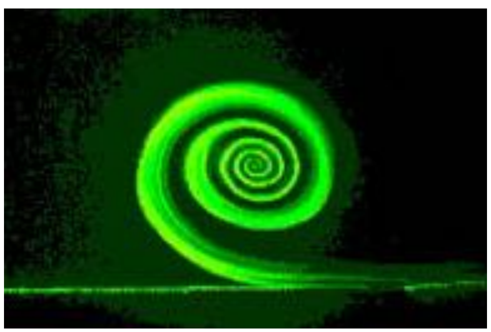


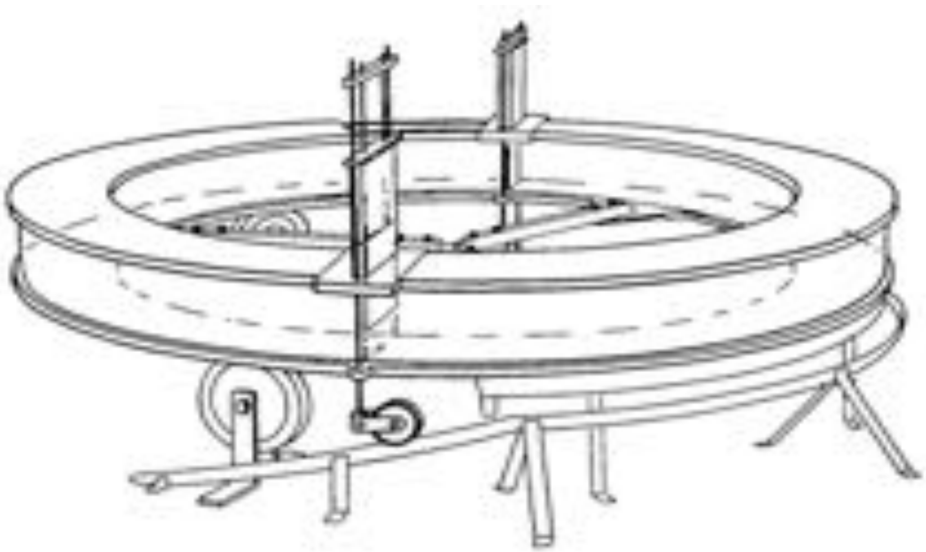

I'VE A FEELING WE'RE NOT IN KANSAS ANYMORE

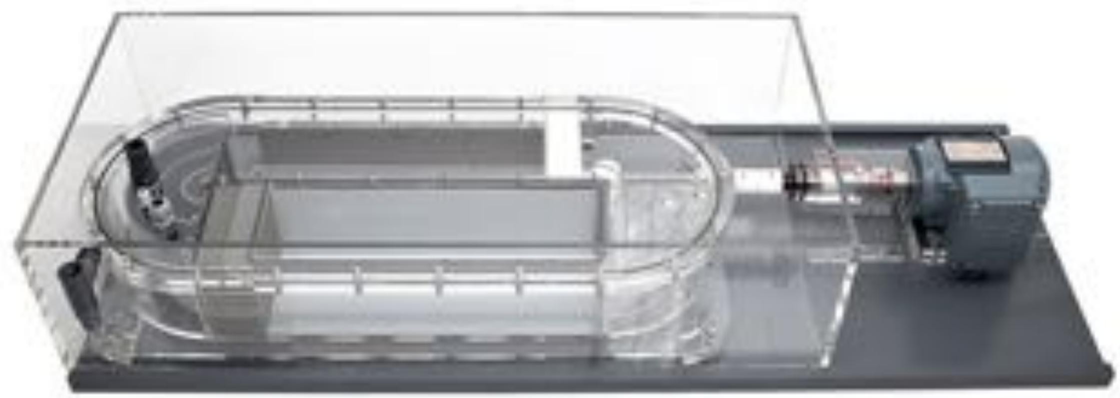
Motivation

Understand the relationship between turbulence and fish habitat choices/swimming

Develop a relevant framework for physical parameterization of turbulence that best describes the flow fish experience

Relate this physical framework to biological parameters that characterize fish experience



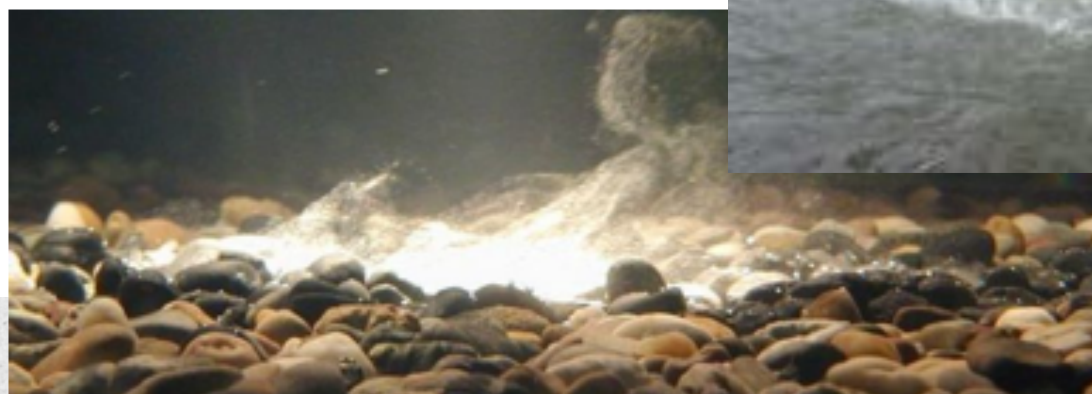
Studies of Fish Swimming

Focus on kinematics, hydrodynamics, energetics, physiology and optimization questions in artificial environments of low/ no variance in the flow.

Fishes in aquatic systems experience turbulence

How do fishes respond to typical features of environmental flows?

Turbulence arises from flow interacting with structures –
bottom topography, banks, protruding structures.



-> Wide range of results.

Negative effects of eddy-dominated flow on fishes

Fish avoid high levels of turbulence in laboratory trials.

Fish swimming performance is reduced by higher turbulence intensity (e.g. Pavlov et al. 1982, 1983, 2000).

Stronger swimmers are found in more energetic flows.

More turbulent flows increase oxygen consumption (Enders et al. 2003)

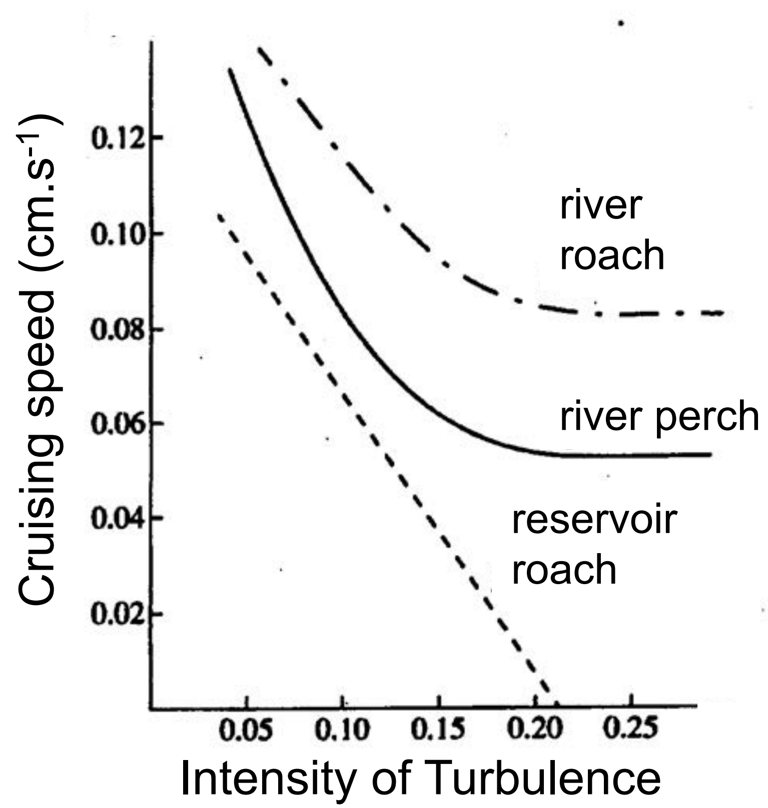
A Common Feature

Turbulence can challenge control of body posture and swimming trajectories.

Swimming speed is reduced by turbulence.

Species Studied: Roach, gudgeon, chub, perch, goldfish, grayling, various salmonids, various reef fishes.

Co-variates: fish size, river/lake populations, fasted/fed, life history stage.



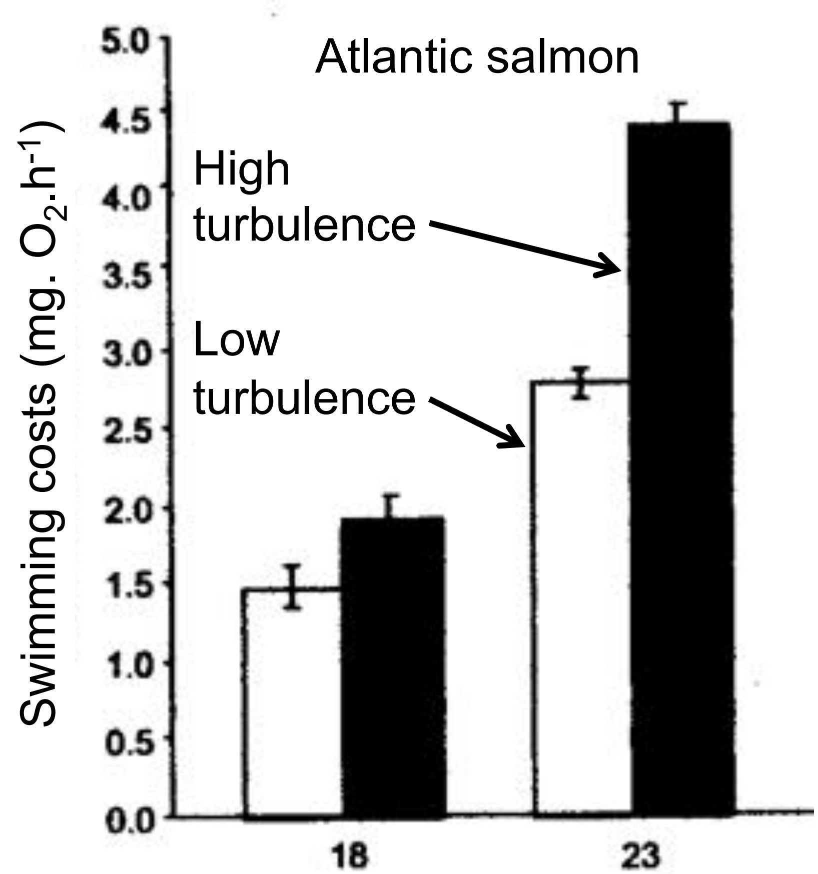
Pavlov et al. 2000. J. Ichthyol. 40 suppl 2: S232-S261.

A Common Feature

Turbulence can challenge control of body posture and swimming trajectories.

Energy is expended in controlling stability.

Species Studied: sockeye salmon, Atlantic salmon.



Enders et al. 2003. Can. J. Fish. Aquat. Sci. 60:1149-1160.

A Common Feature

Fish avoid high levels of turbulence in binary laboratory trials.

Stronger swimmers choose more turbulent flows in
binary tests.

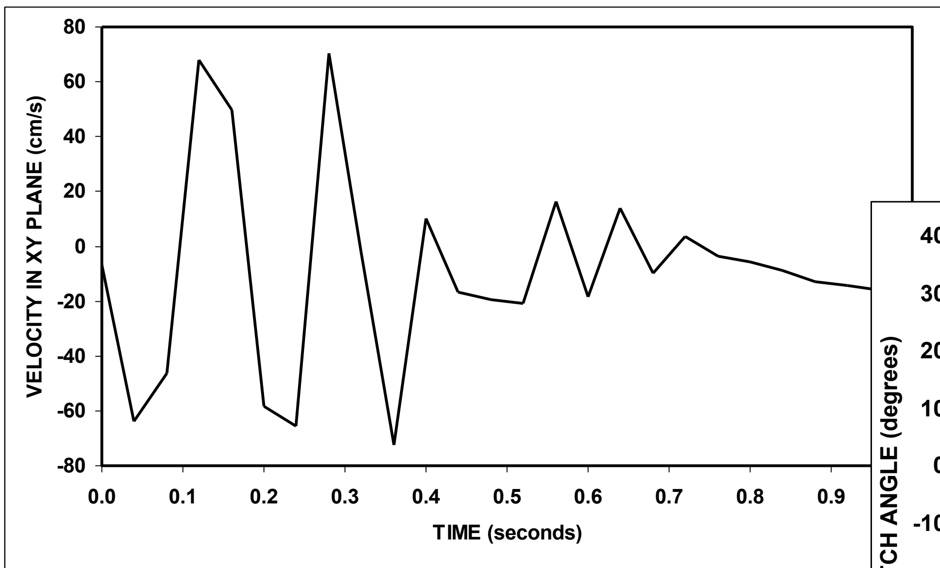
Species Studied: Roach, gudgeon, chub, perch, goldfish, grayling, various salmonids, various reef fishes.

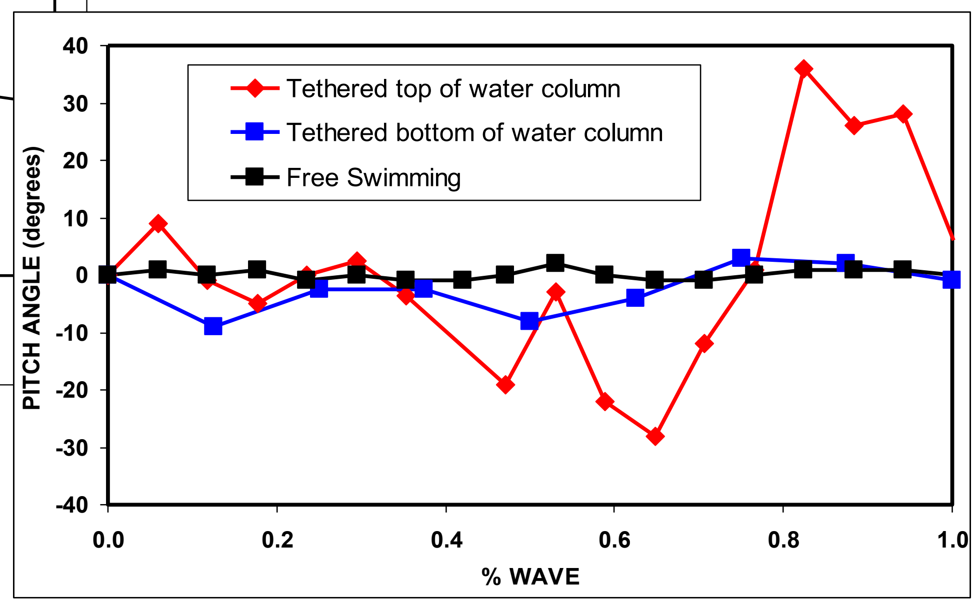
Various authors.

A Common Feature

Turbulence can challenge control of body posture and swimming trajectories.

Spottail shiner - waves created by boat on sandy beach.

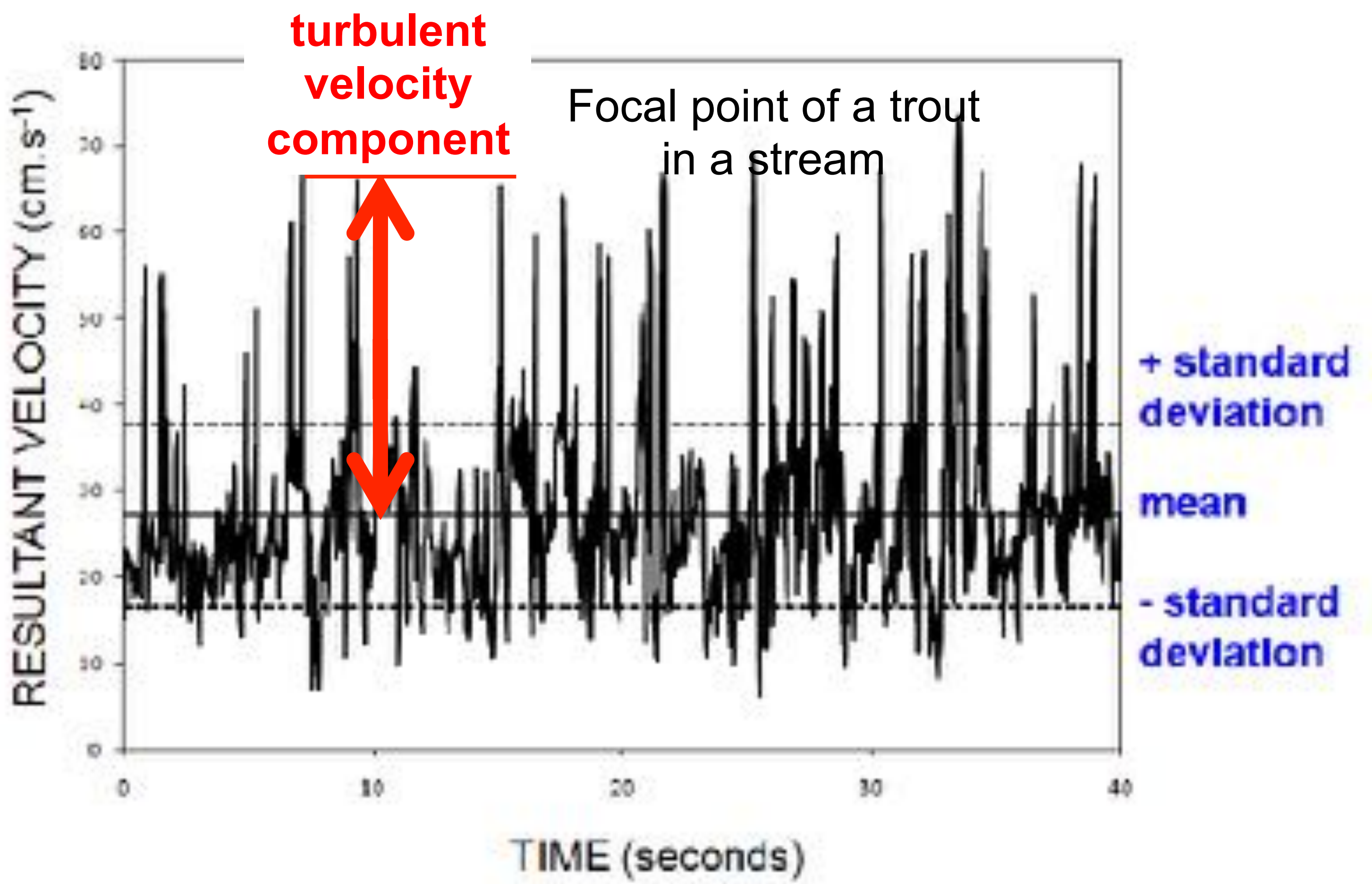




Cotel, A. J. and Webb, P. W. 2004.

MEASURING TURBULENCE

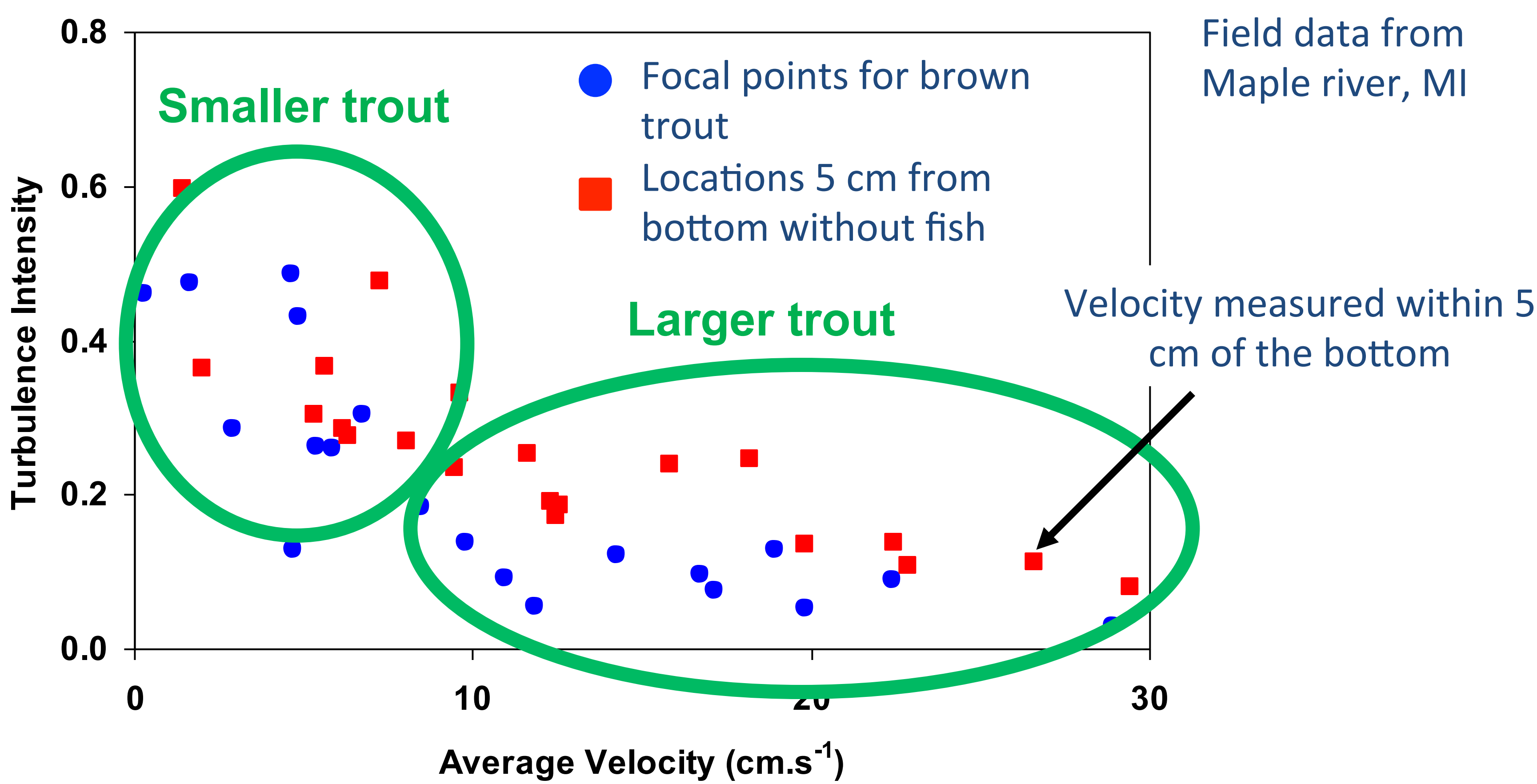
with Acoustic Doppler Velocimetry



Turbulent Intensity = TI = standard deviation / mean velocity

Turbulent Kinetic Energy = TKE = 0.5 (standard deviation)^2

Fishes choose regions of lower turbulence intensity

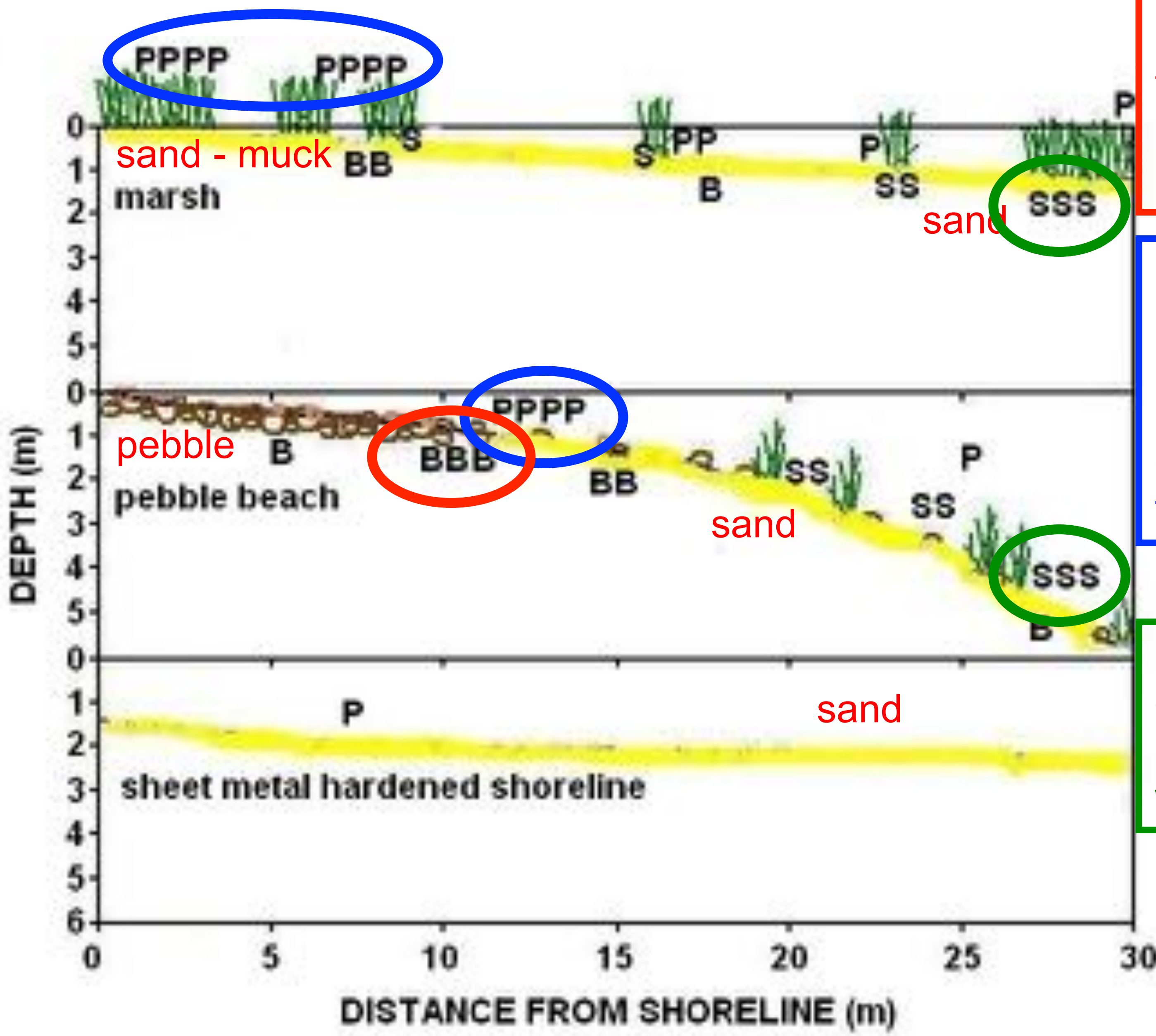


Field data from Maple river, MI

Turbulence Intensity = <u>standard deviation of current velocity</u>
mean current velocity

Cotel, A. J., Webb, P. W. and Tritico, H. 2006. Do trout choose habitats with reduced turbulence? Trans. Amer. Fish. Soc. 135;610-619

Fishes - # letters – relative abundance



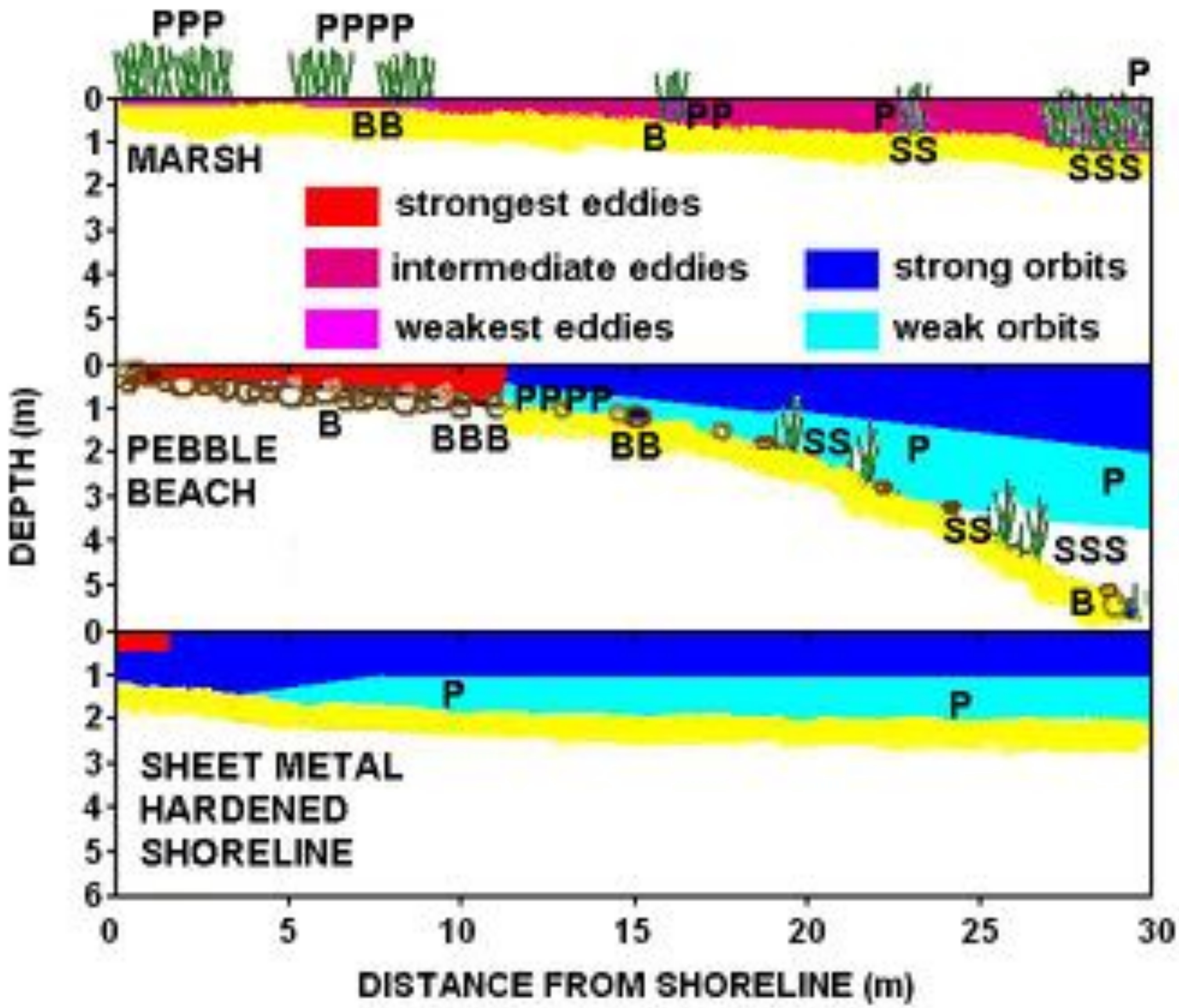
B – benthic fish guild, most abundant on pebble at pebble-sand transition on rocky beach where pebble provides refuges.

P – pelagic fish guild, most abundant in marsh and on sand at pebble-sand transition on rocky beach – more turbulent situations.

S – slow-water fish guild, most abundant in deeper, slower open water or among plants.

Webb, P. W., A. J. Cotel and L. A. Meadows. 2010. Waves and eddies: effects on fish behaviour and habitat distribution. *In* Fish LocomotionScience Publishers, Enfield, NH, pp. 1-39

RESULTS – Biotic Distribution and Eddy Strength

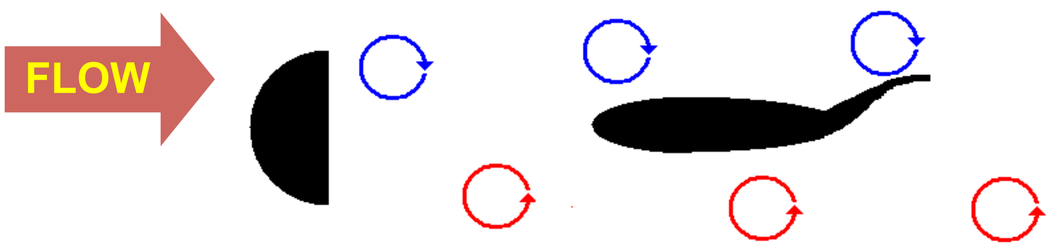


Uncertain/positive effects of eddy-dominated flow on fishes

Unsteady flow created by wavy walls or jets.

Swimming performance unaffected by intensity of turbulence.

Swimming performance improved in unsteady flow.



Nikora V I, Aberlee J, Biggs B J F, Jowett I G, and Sykes J R E. 2003. *Effects of fish size, time to fatigue, and turbulence on swimming performance: a case study of Galaxias maculatus*. J. Fish Biol 63:1365-1382.

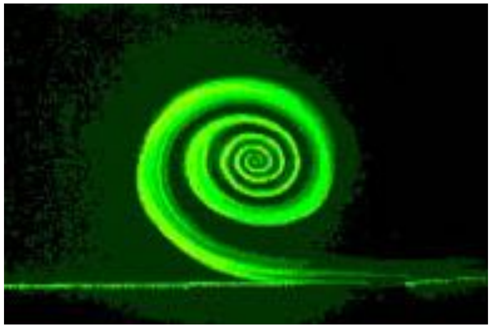
Perry, R., Farley M., Hansen G., Morse J,, and Rondorf D. 2005. *Turbulence Investigation and Reproduction for Assisting Downstream Migrating Juvenile Salmonids, Part II of II; Effects of Induced Turbulence on Behavior of Juvenile Salmon*. BPA Report DOE/BP-00007427-1. http://www.efw.bpa.gov/publications/D00007427-1.pdf

Liao, J., Beal, D. N., Lauder, G. V. and M. S. Trianyafyllou. 2003b. *The **Kármán gait**: Novel body kinematics of rainbow trout swimming in a vortex street.* Journal of Experimental Biology 206: 1059-1073.

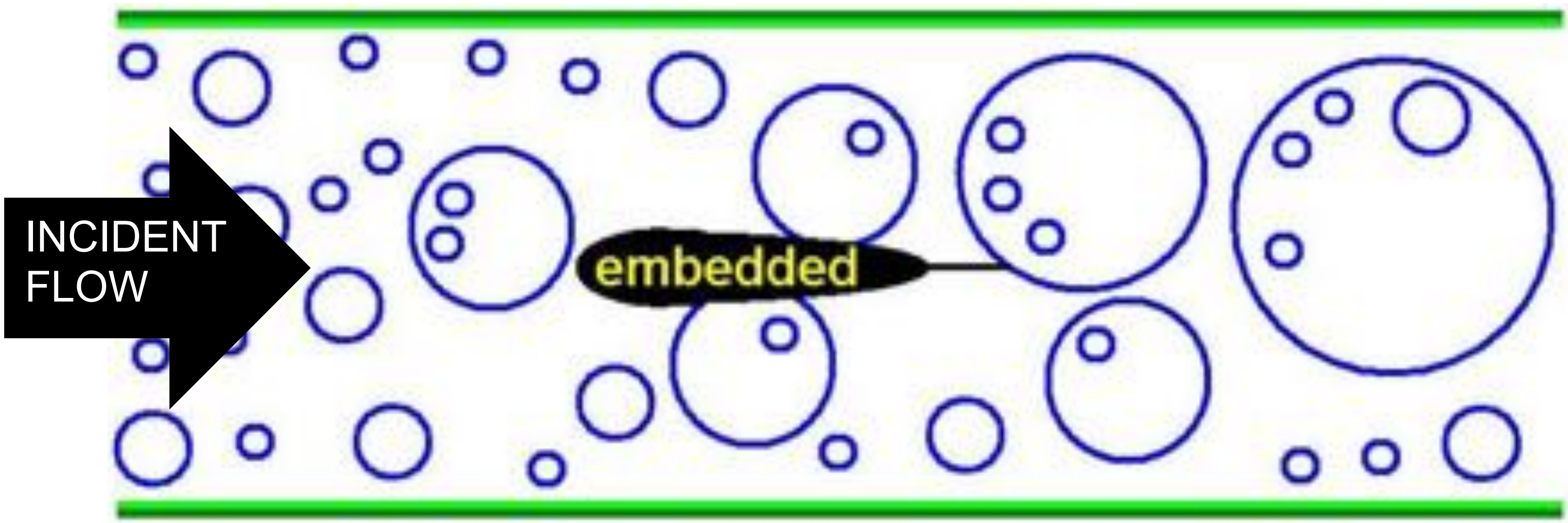
Some negative effects of turbulence, some positive…

WHY???

Could it be the way we define turbulence?



Turbulent Flow is comprised of eddies in which a fish is embedded

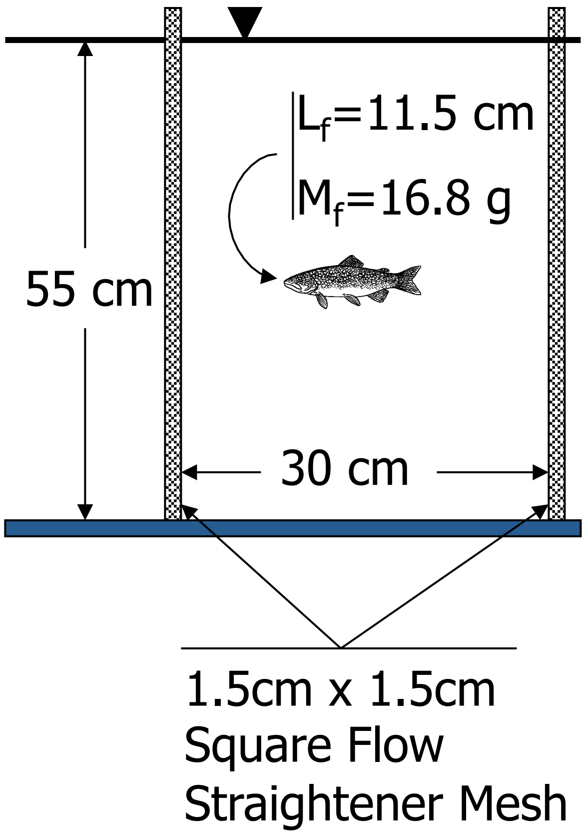


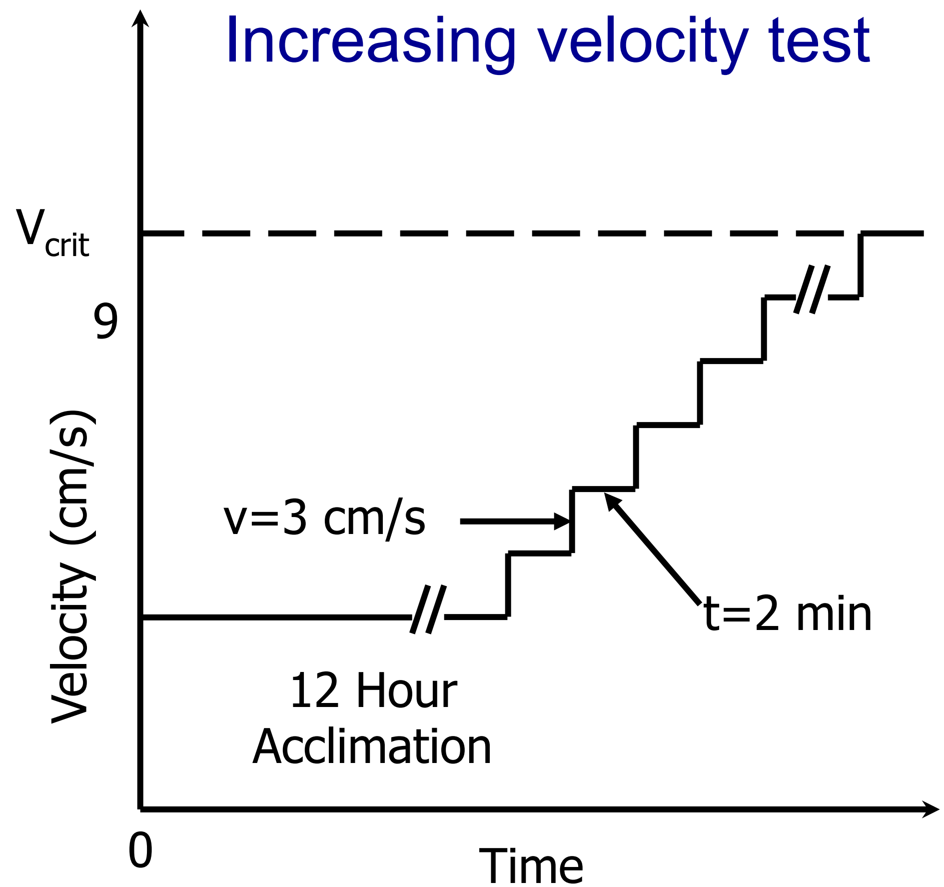
Incident Flow and Embedded Body interactions linked by:

Relative Spatial Scale - Eddy size relative to the size of the embedded body (from larvae to adults).

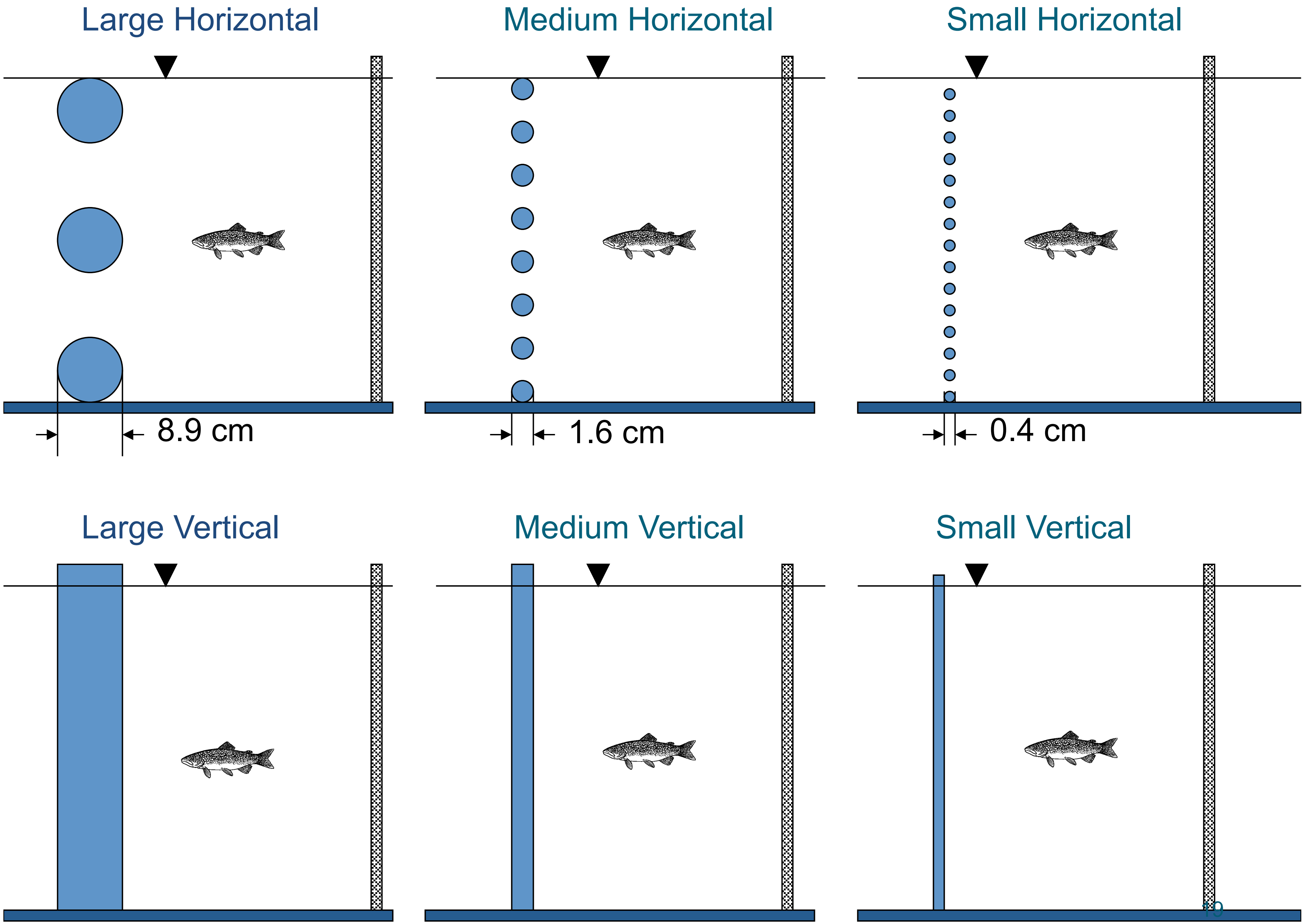
Relative Time Scale – Eddy frequency and periodicity relative to response latency of embedded body.

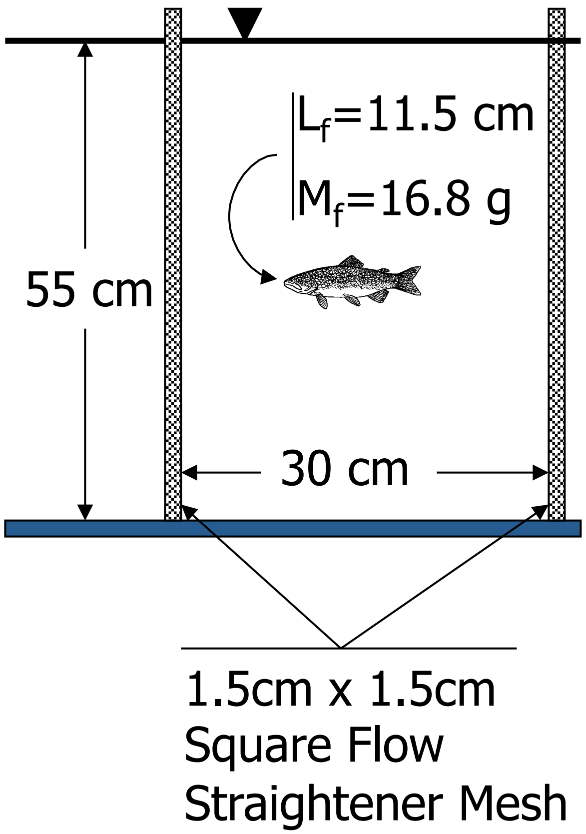
Lab experiments - large recirculating water tunnel

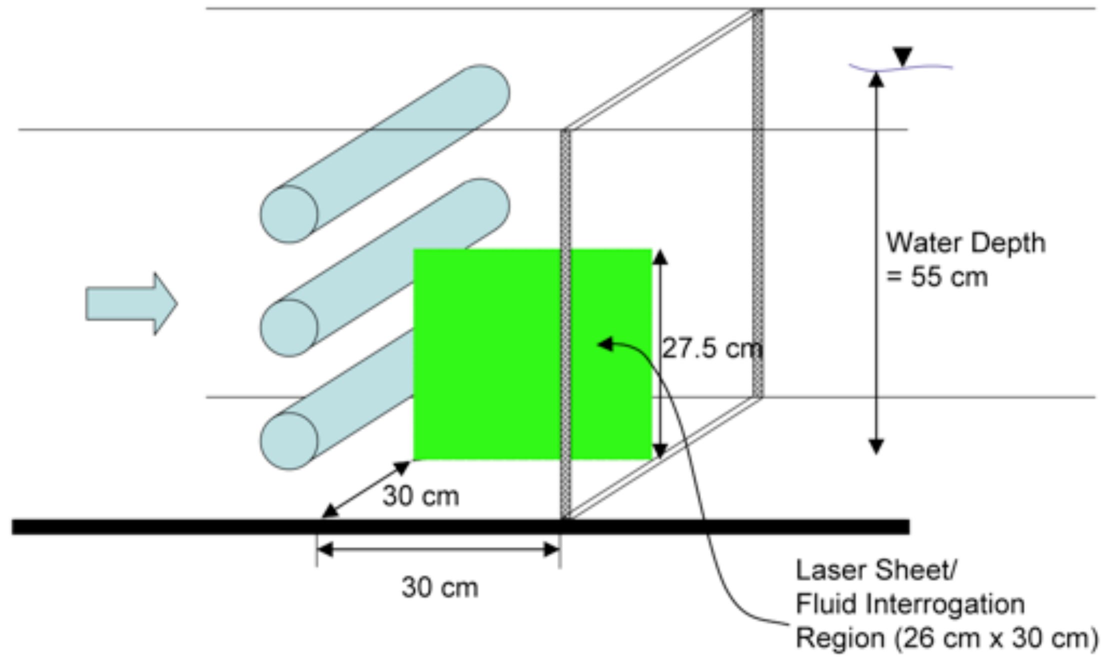


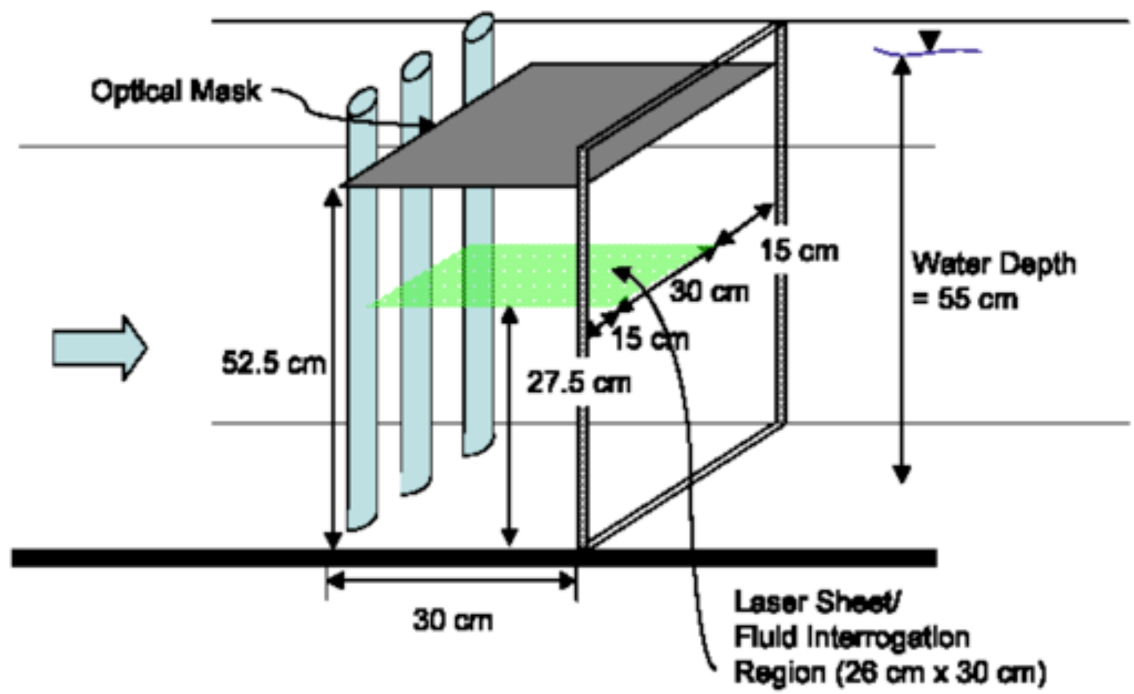


Water Temp = 20.5 °C


Large Horizontal
Medium Horizontal
Small Horizontal
8.9 cm
1.6 cm
0.4 cm
Large Vertical
Medium Vertical
Small Vertical

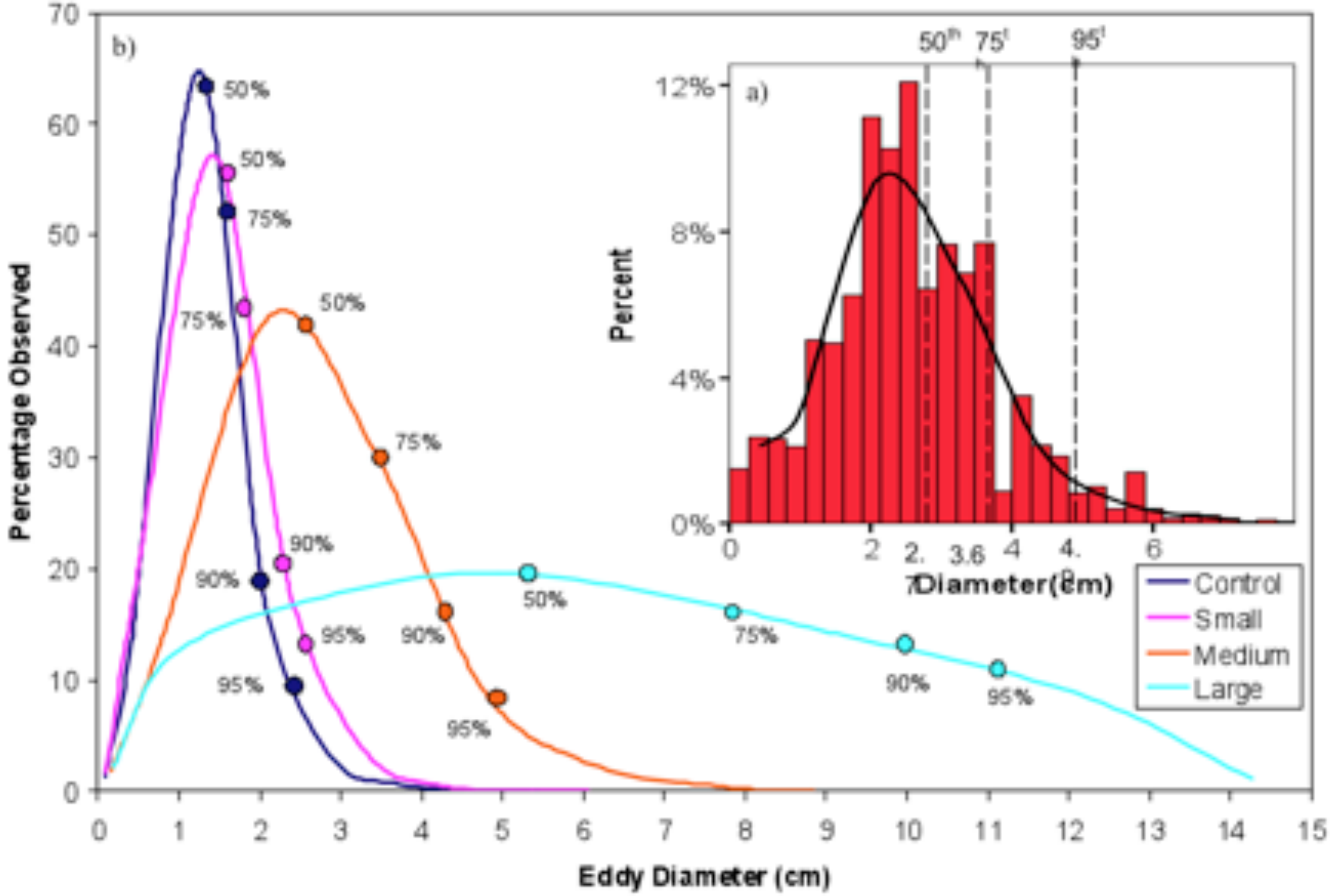




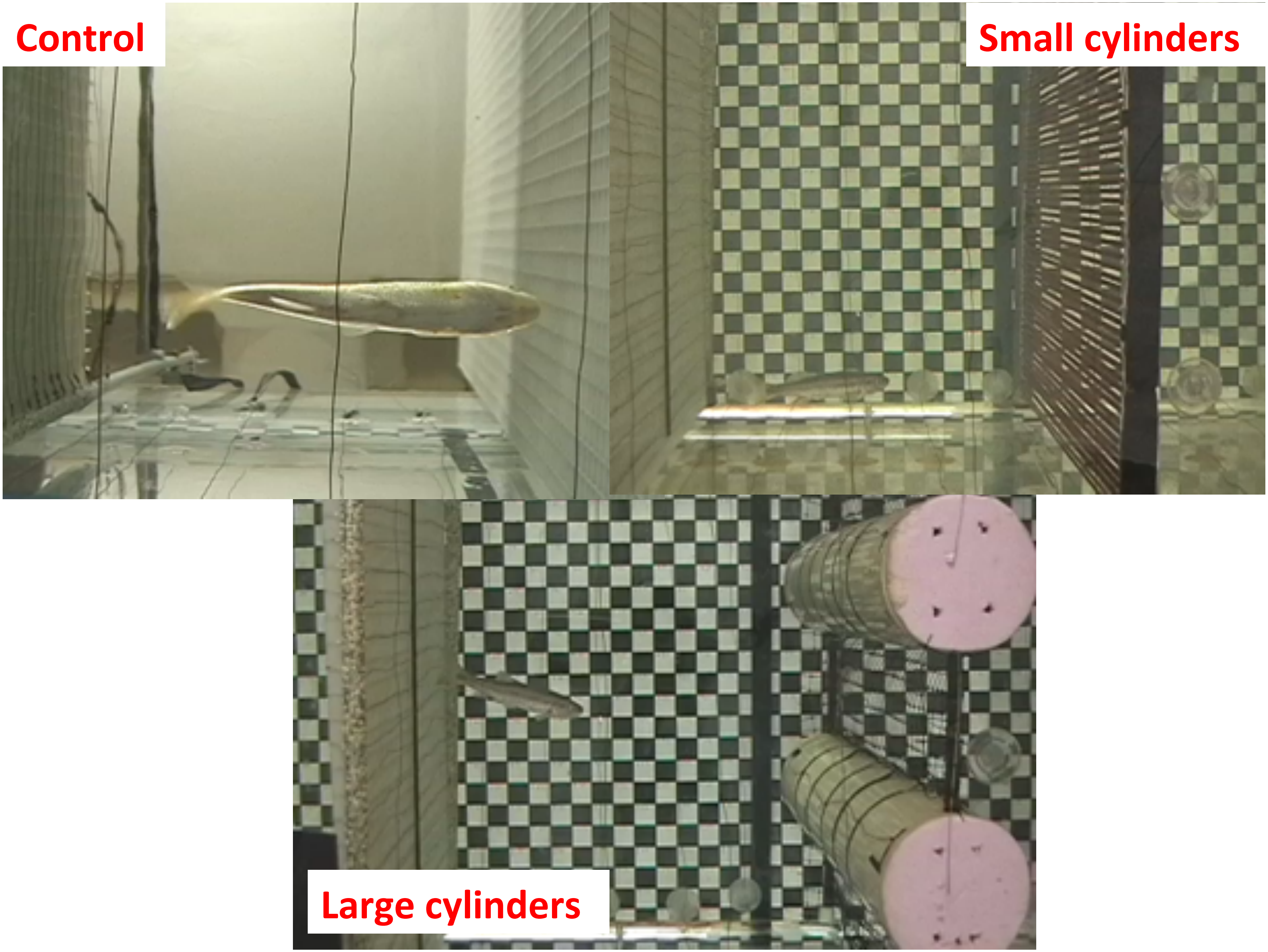


Technique: Particle Image Velocimetry

Results – eddy sizes

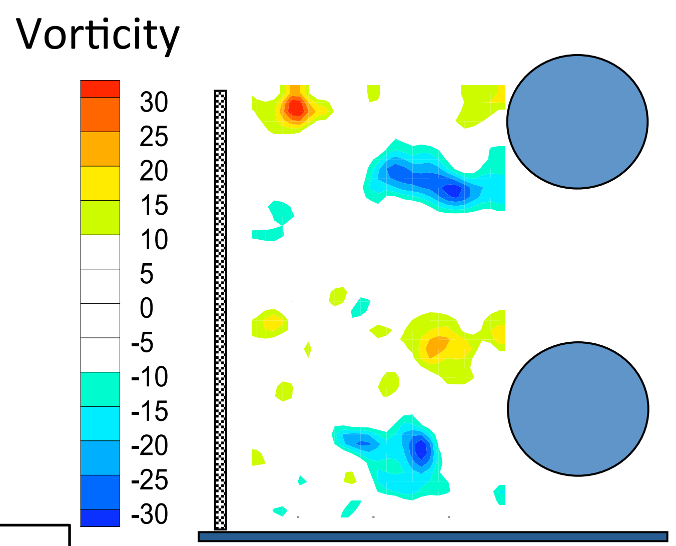


Eddies identified using Drucker and Lauder (1999) from PIV data

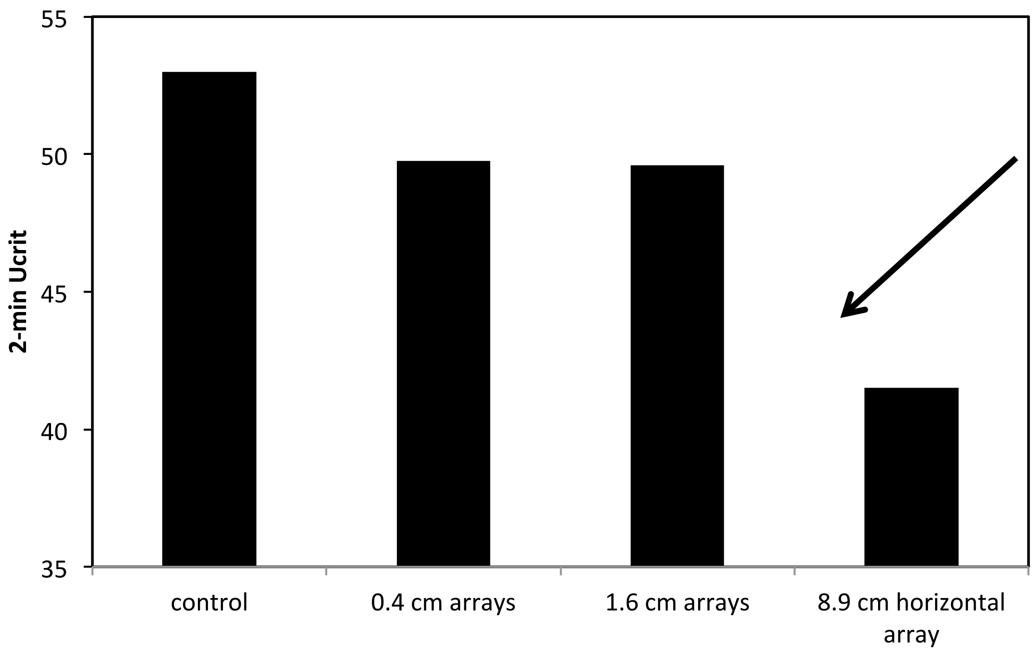

Control
Small cylinders
Large cylinders

Results – fish performance

Increasing velocity test with creek chub, 11.5 cm total length



Horizontal Cylinders



Occurrence of eddies up to 8.4 cm in diameter shed by the large cylinders significantly reduced U_{crit}

Tritico and Cotel (2010)

Relevant parameters

Flow Parameters	Definition	Value
Length scale	Eddy diameter identified from PIV data	1 – 8 cm
Circulation	$\Gamma = \omega_e A_e$	5 – 640 cm^2/sec
Momentum flux/thrust	$T = \rho V_e^2 L_e^2$	25 to 409,600 cm^4/sec^2

The range is for the different sets of experiments performed, from the small to the large cylinders configurations, with the highest water tunnel velocity (56cm/s).

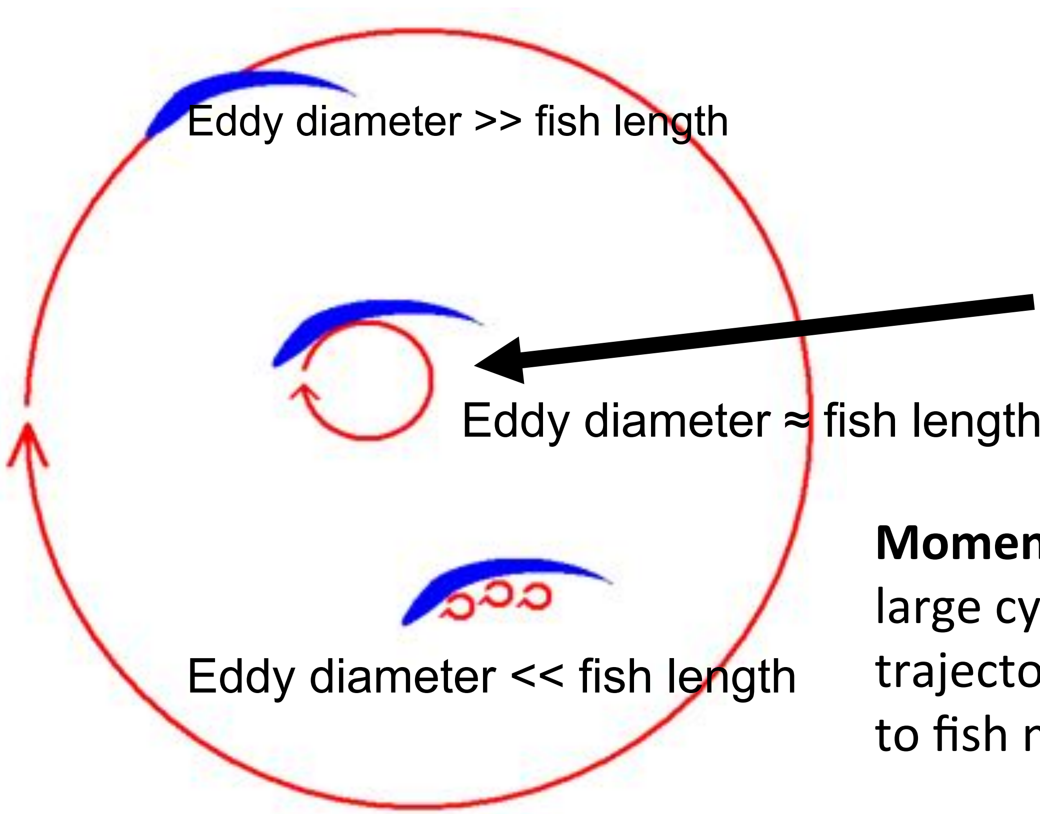
Fish Parameters	Definition	Value
Length scale	Body length	11.5 cm
Circulation	$\Gamma = \omega_f A_f = V_f L_f$	483 cm^2/sec
Momentum flux/thrust	$T = \rho V_f^2 L_f^2$	233,289 cm^4/sec^2

Based on fish lowest critical swimming speed (42 cm/sec).

Cotel and Webb (2015)

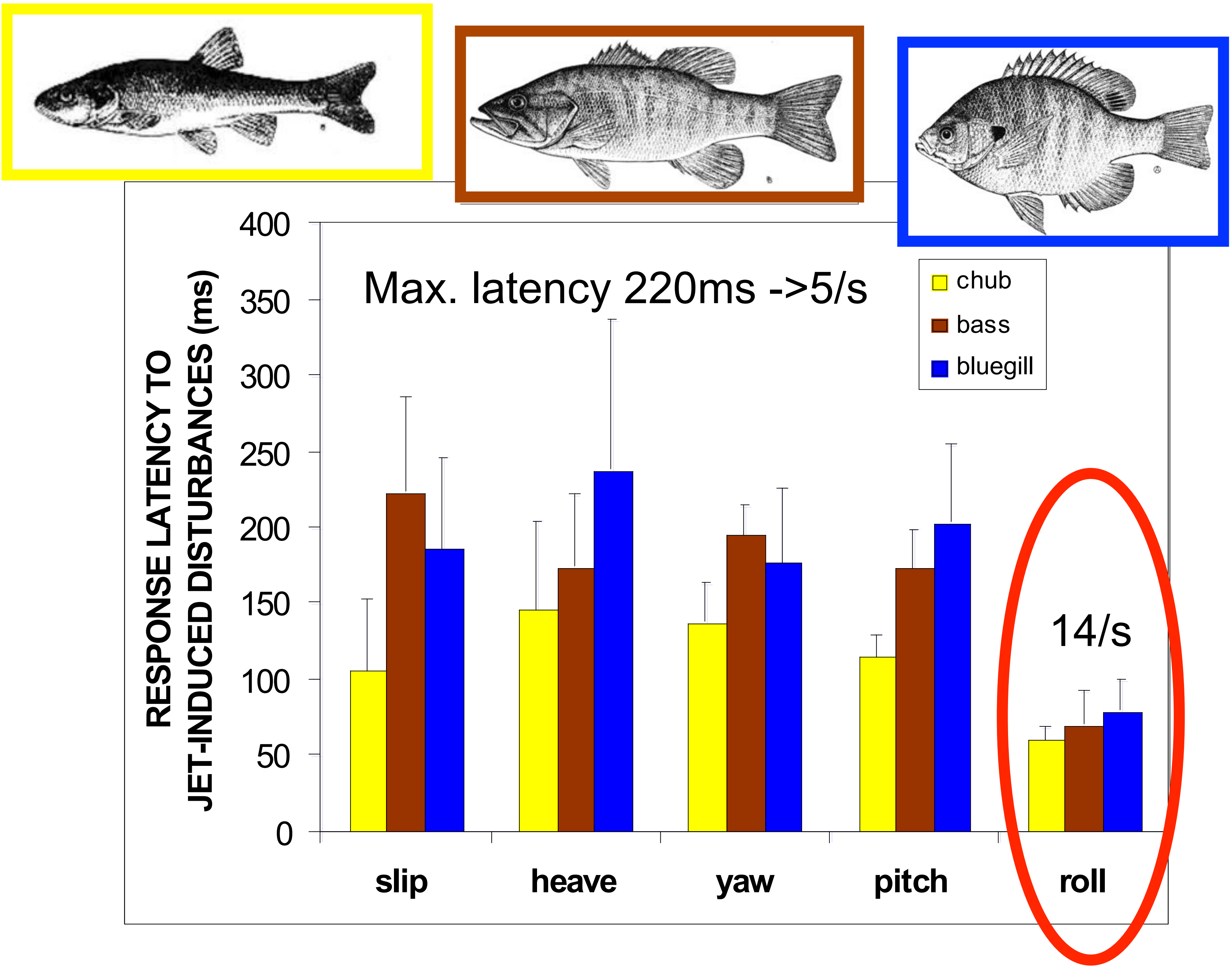
Comparison – Flow to Fish

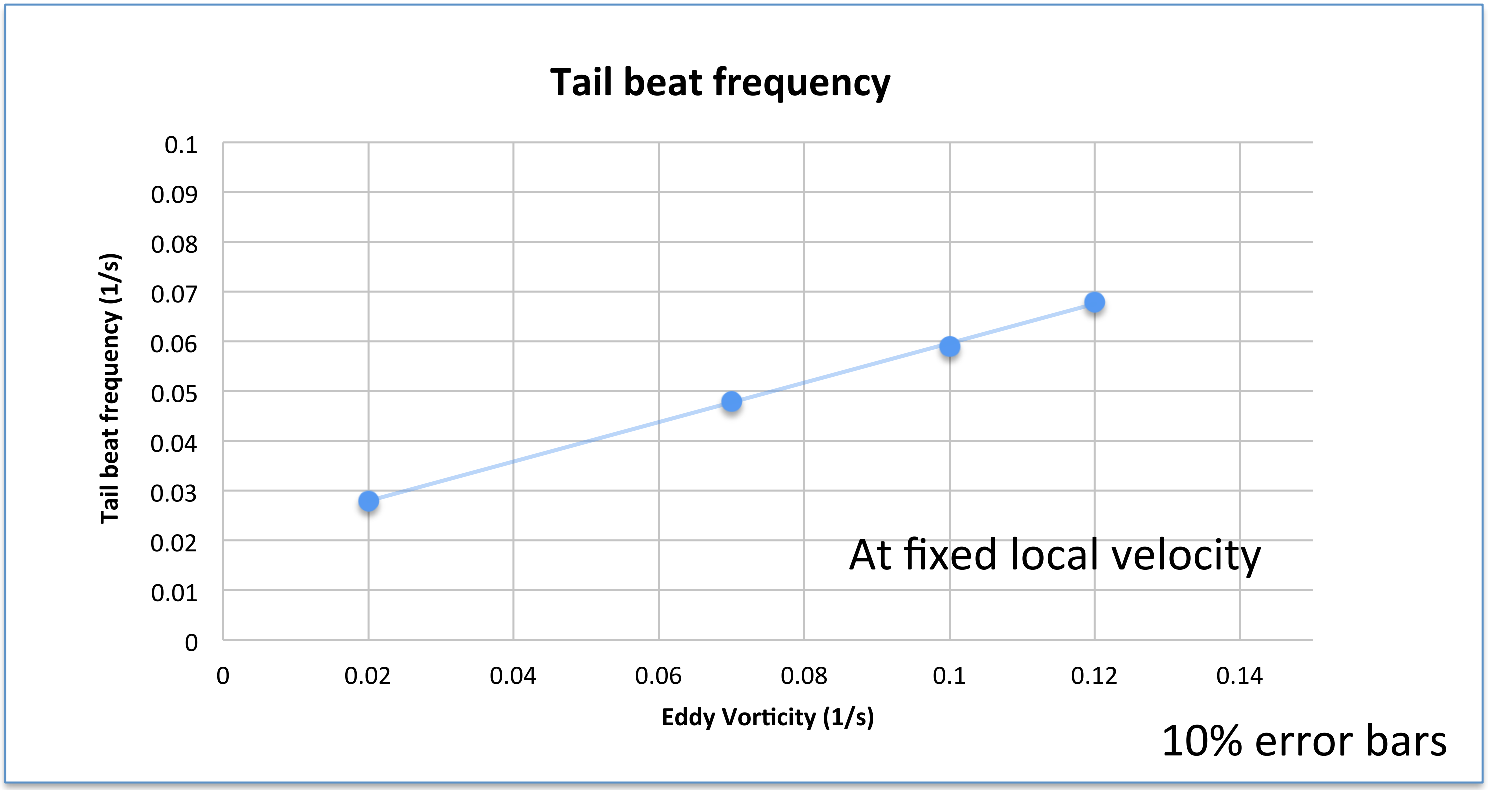
Scenario	Ratio of lengthscale	Circulation ratio	Momentum ratio
Small cylinders	0.09	0.01	0.0001
Medium cylinders	0.25	0.09	0.0087
Large cylinders	0.69	1.32	1.76



Eddies of the range 0.5 to 1 fish length affect swimming.

Momentum also important – only the large cylinder case poses stability and trajectory challenges as reflected in the flow to fish momentum ratio.


Max. latency 220ms ->5/s
chub
bass
bluegill
RESPONSE LATENCY TO
JET-INDUCED DISTURBANCES (ms)
400
350
300
250
200
150
100
50
0
14/s
slip
heave
yaw
pitch
roll



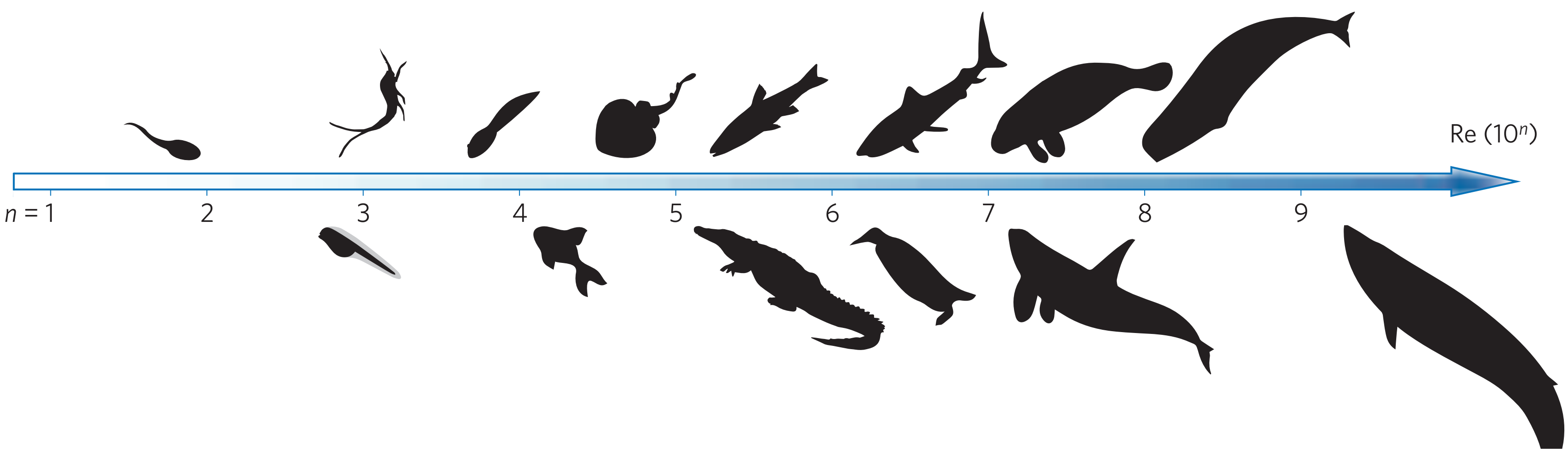
STRONG correlation between tail beat frequency and eddy vorticity

Tritico (2008)

Aquatic locomotion - Moving away from Strouhal number

- St = fA/u where f is the tail beat frequency, A the tail beat amplitude and u the local velocity. It mixes input and output variables!

- Gazzola et al. (2014): Unifying principle for locomotion -> Swimming Number.
- Valid over 8 orders of magnitude of Re.

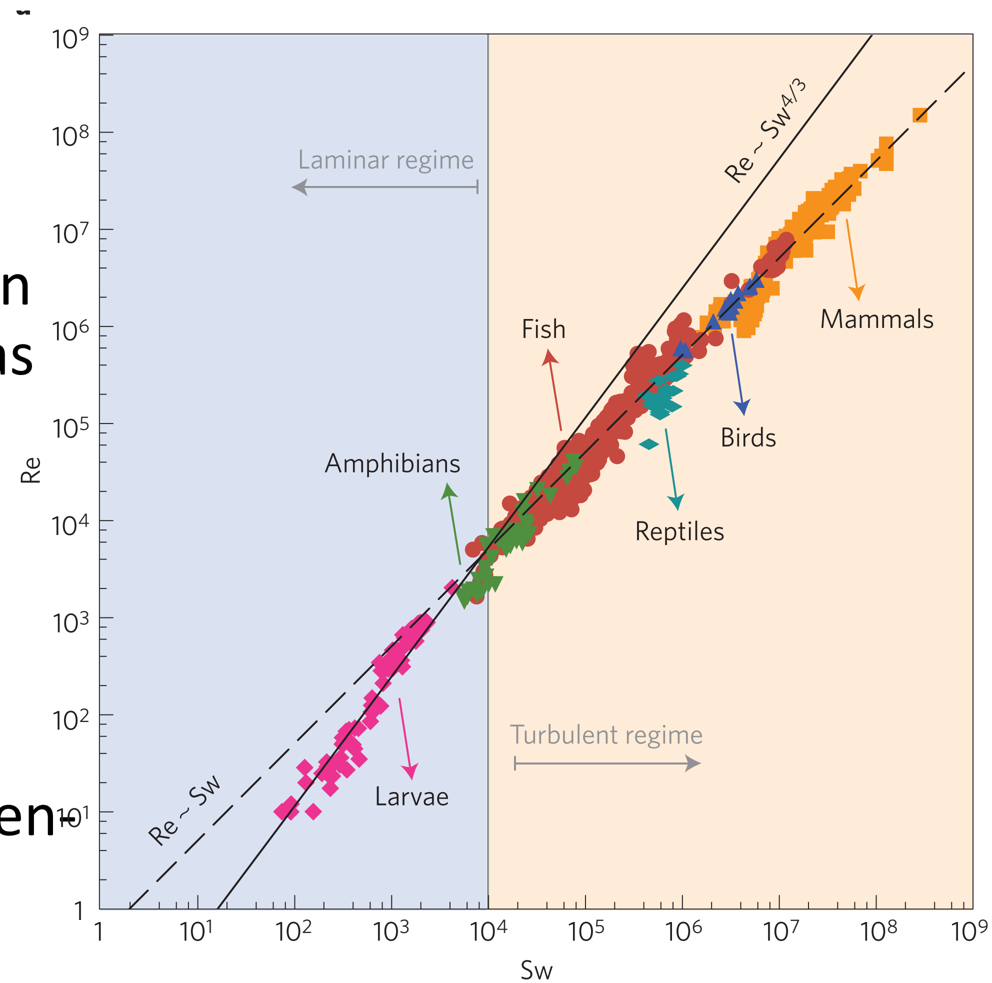


Swimming number

- Sw = fAL/ν

- Laminar (Balance between skin friction and thrust) - Re goes as $Sw^{4/3}$
- Turbulent (Balance between pressure drag and thrust): Re goes as Sw.

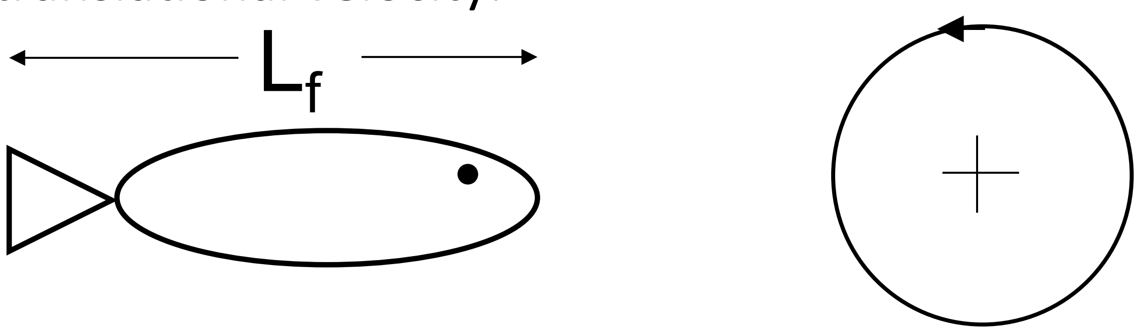
- Locomotion described by dimensionless parameters only!



More on time scale!

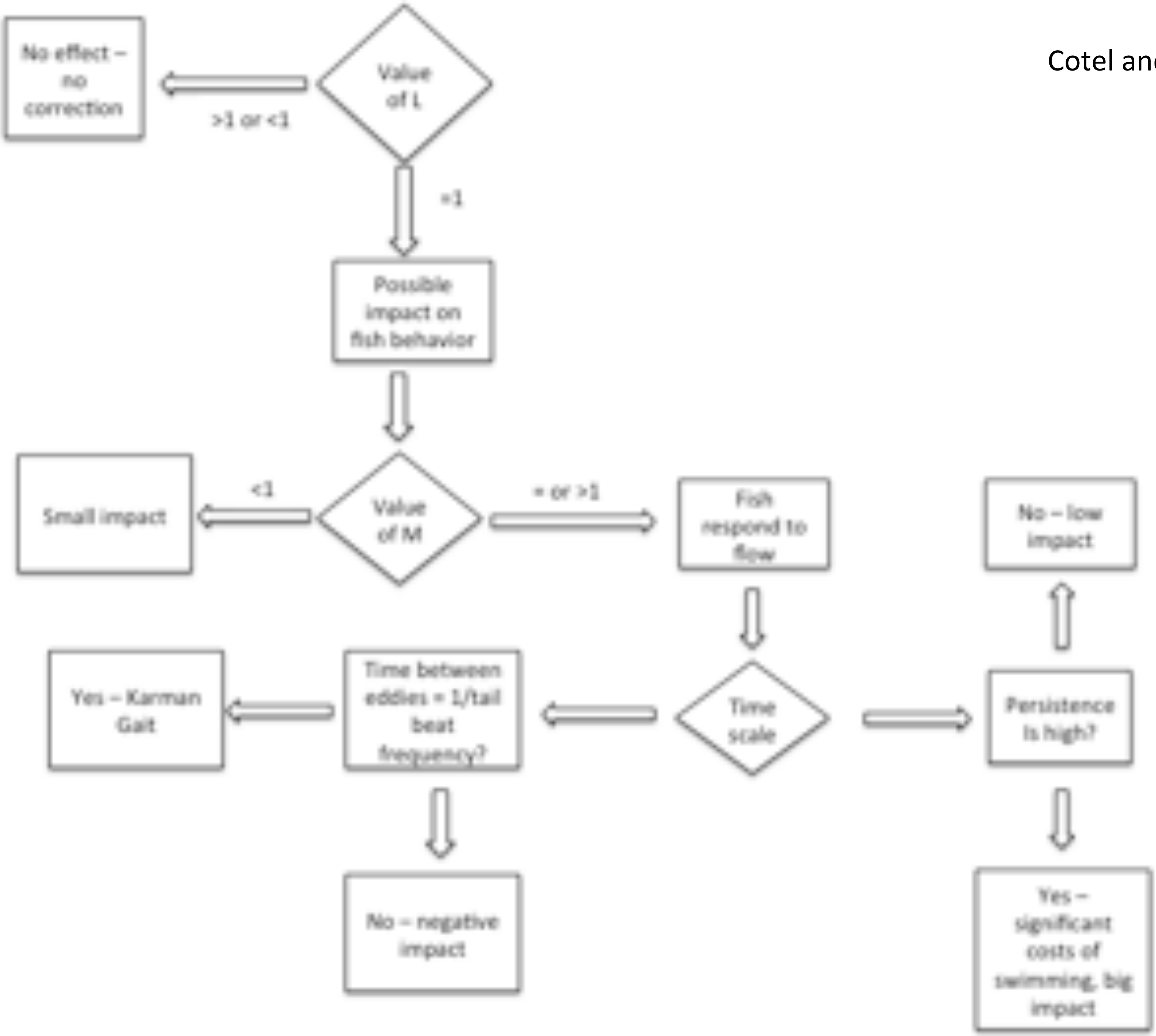
- How long fish are interacting with turbulent eddies will impact their swimming performance and habitat choice.

- Persistence parameter (Cotel, 1995) defines the stationarity of vortices with respect to a surface, i.e. ratio of eddy rotational to translational velocity.



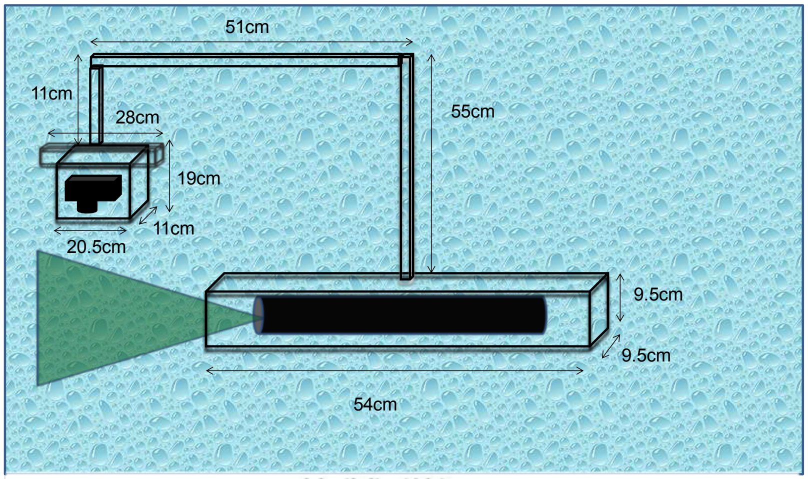
- It would represent here how long fish are experiencing significant interaction with eddies.

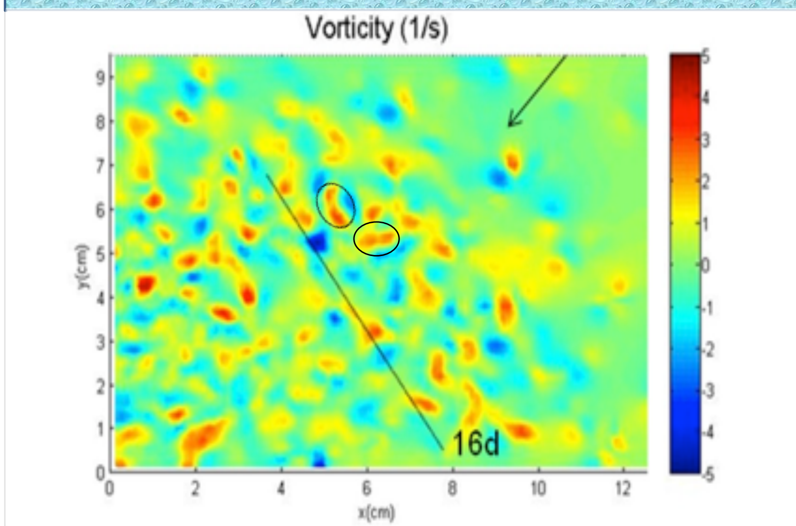
Cotel and Webb (2015)

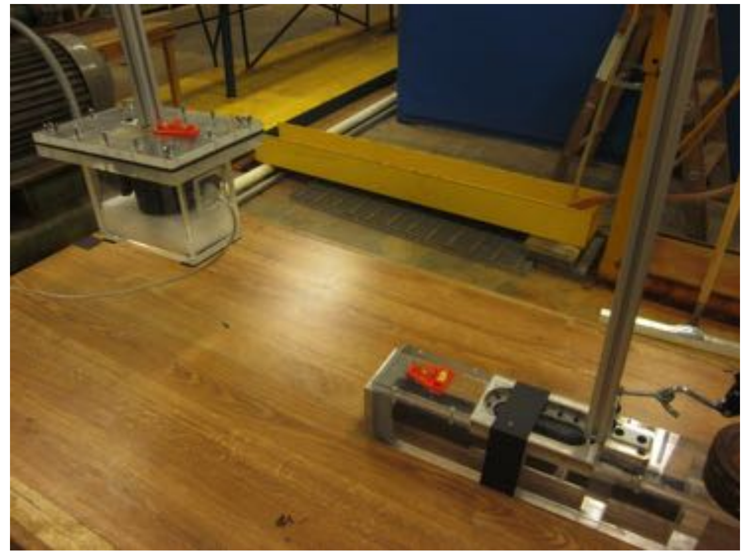


Field measurement techniques

- Underwater PIV



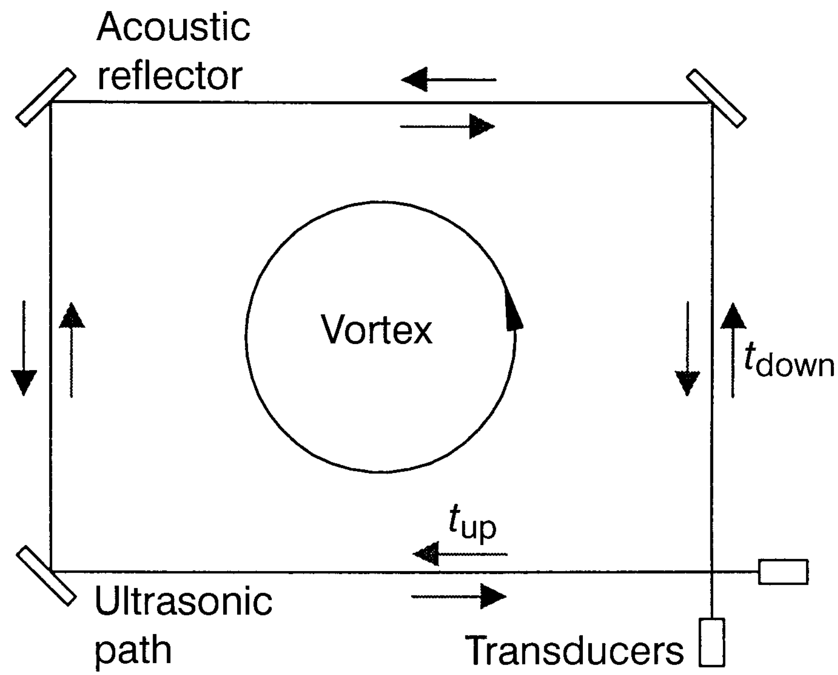




Clarke, Tritico and Cotel (2007)

Direct measure of circulation by ultrasound

- Measures transit time of ultrasonic pulses traveling in the direction of vortex rotation and against it.
- Tested in air and water
- Could be installed in rivers or man-made structures (e.g. fish passageways) as monitoring devices and used as a sensor for adaptive management strategies.



Johari and Durgin (1998)

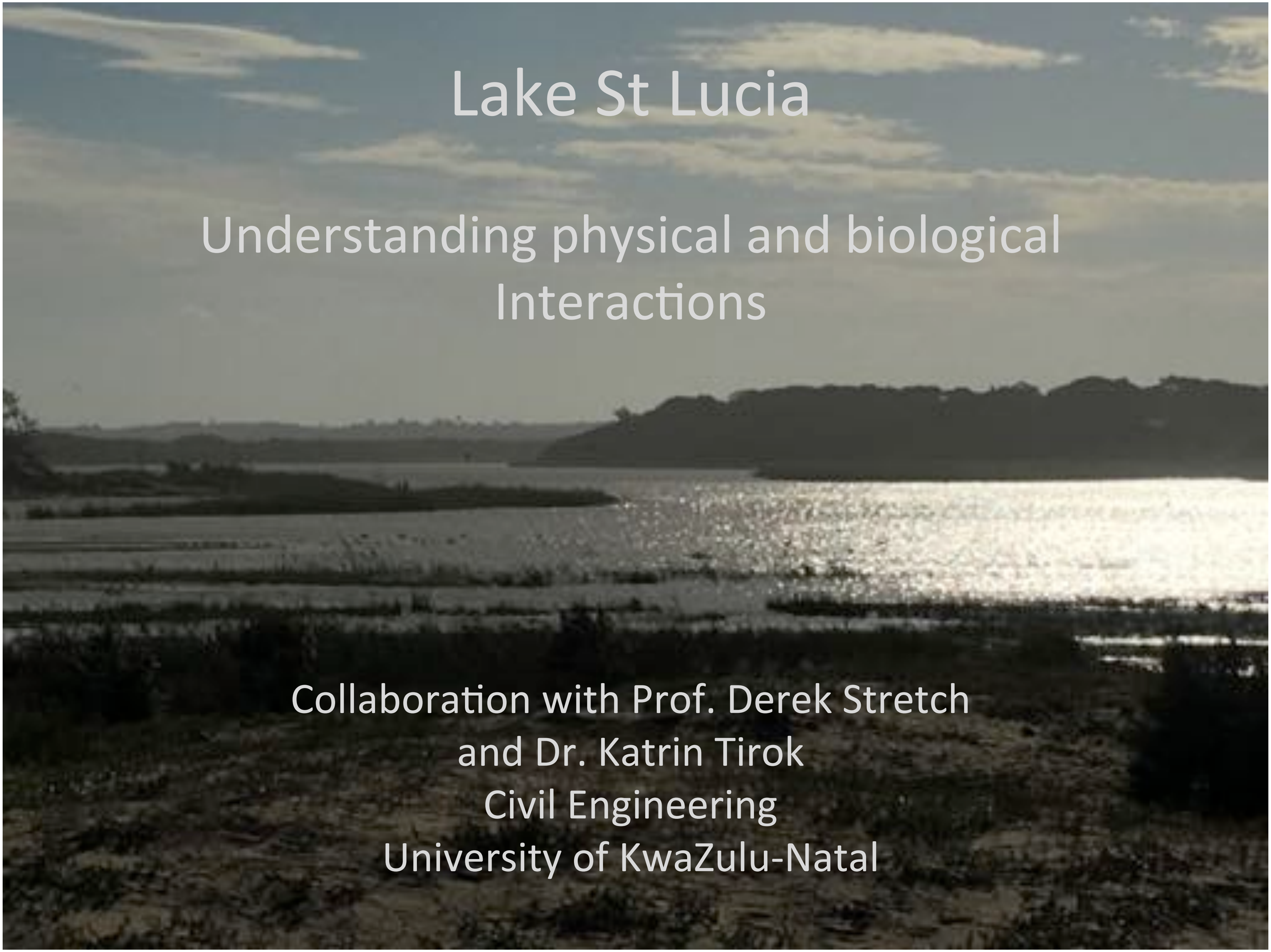
Summary

- Turbulence measured in different ways can lead to contradictory biological impacts.

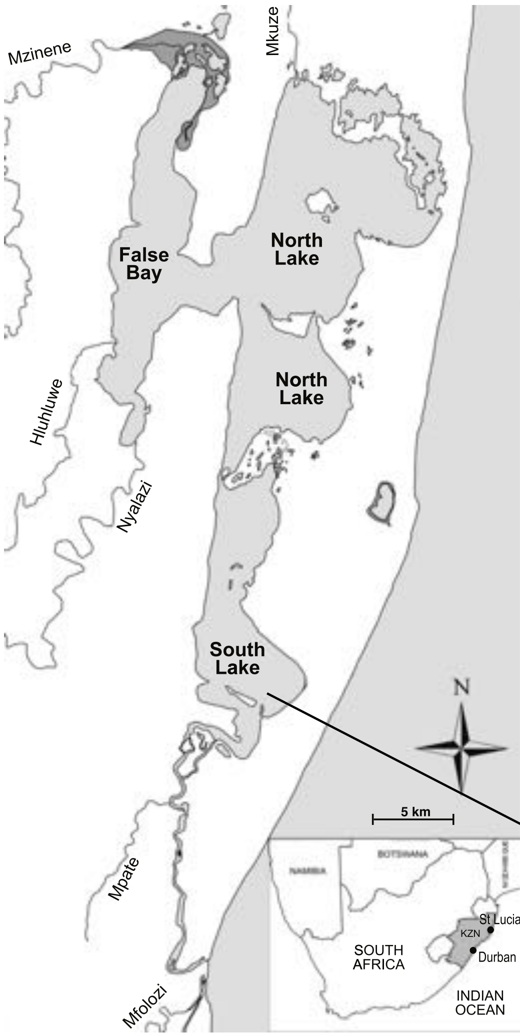
- Need unifying reference frame to evaluate fish responses to turbulent flows -> A **physical** framework to link flow conditions to fish responses is proposed.

- Based on dimensionless parameters to allow applications for a wide range of length and time scales.

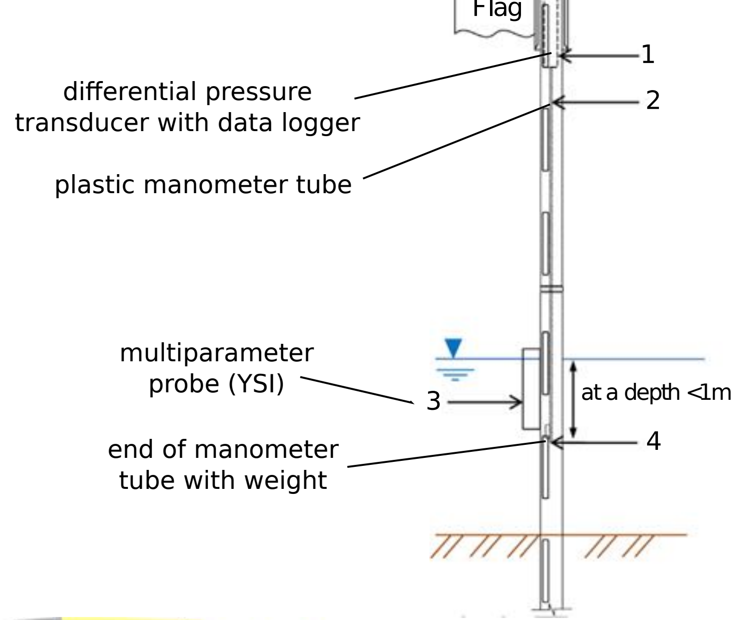
- Future steps require the acquisition of more field data using different instruments as there is a need to move away from point measurements.

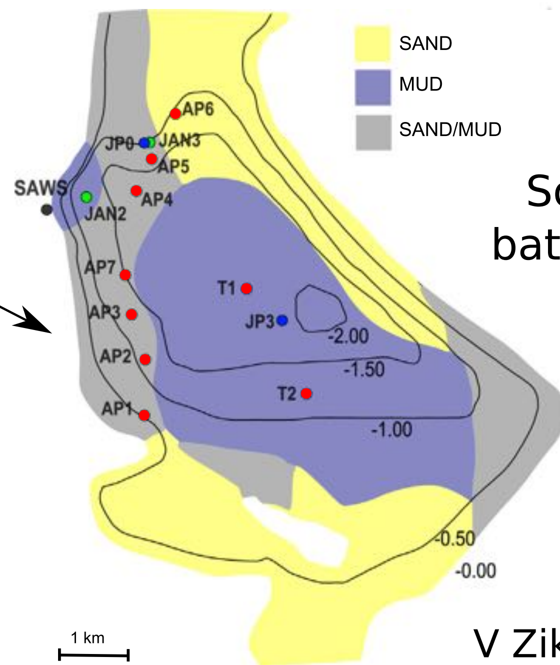

Lake St Lucia
Understanding physical and biological Interactions
Collaboration with Prof. Derek Stretch and Dr. Katrin Tirok
Civil Engineering
University of KwaZulu-Natal

Lake St Lucia



Measurement station

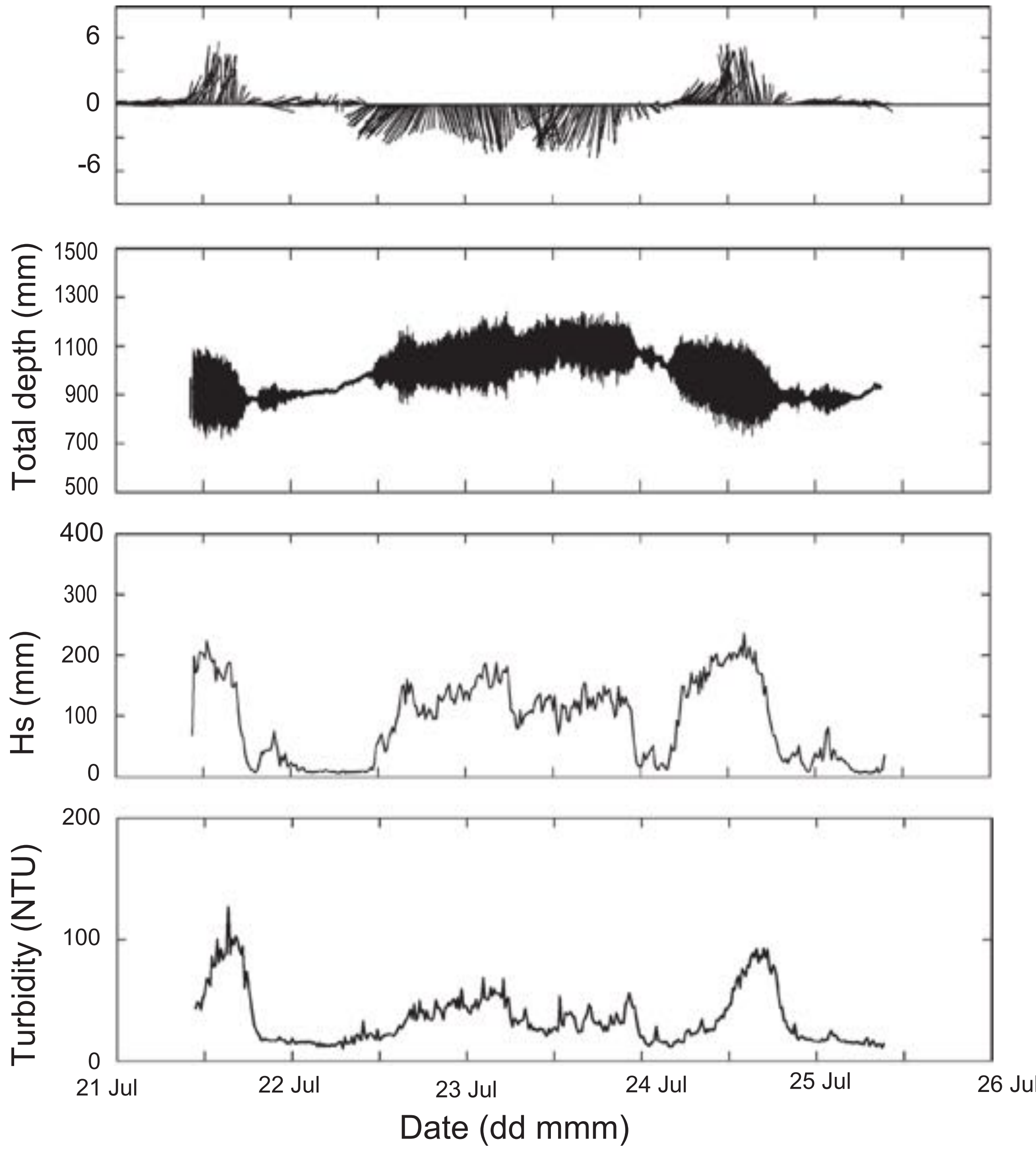




South Lake sediment and bathymetry with positions of measurement stations

V Zikhali, K Tirok & D Stretch (2015)
Continental Shelf Research 108:112-120

Results July 2013 (JP0)



wind vectors

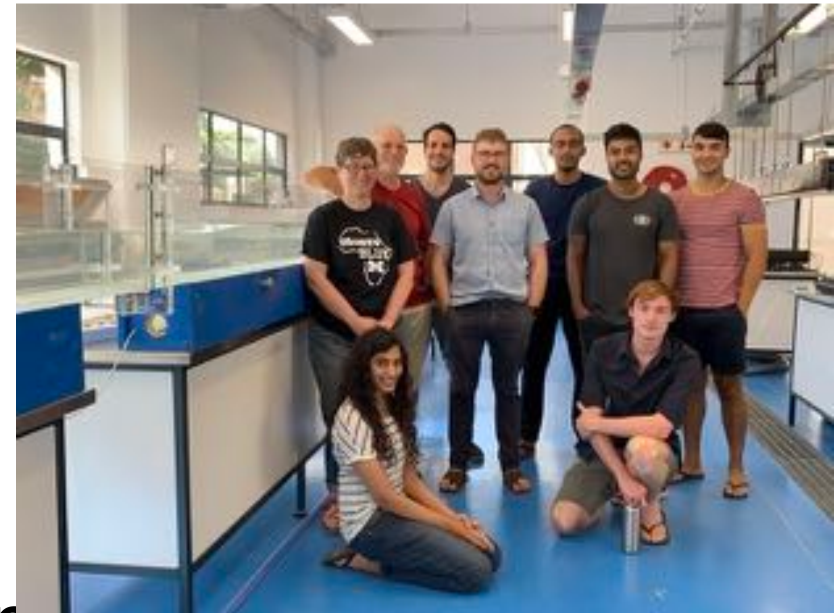
total water depth
with variation
due to waves

significant
wave height

turbidity

SSC (mg/l) = 1.4 NTU
(R^2 = 0.99)

Current collaboration efforts with UKZN



- Small-scale turbulence and wave measurements at St Lucia (data analysis in process)

- Development of a submersible Particle Image Velocimetry system

Questions?