International Conference on Engineering and Ecohydrology for Fish Passage

International Conference on Engineering and Ecohydrology for Fish Passage 2015

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Session B9: Size Matters Even for the Ubiquitous Fish Speed Metric of BL/S

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Size matters even for the ubiquitous fish speed metric of BL/s

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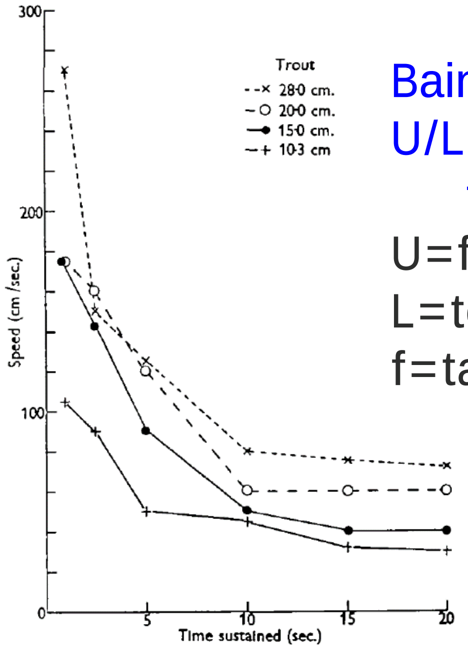
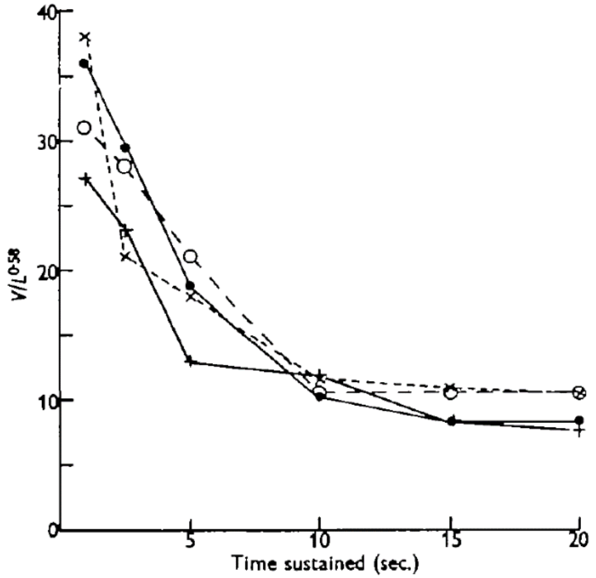
FISH PASSAGE 2015 – Groningen, The Netherlands, June 22-24

Bainbridge on scaling in fish swimming



Bainbridge 1958
U/L= 0.25[L(3f – 4)]
for 3 species
U=fish speed (cm/s)
L=total length (cm)
f=tail beat frequency (Hz)

Graphs for trout from Bainbridge 1960



NOTE: attempt to scale fish speed with fish length: regression with **$1/L^{0.58}$** collapses data better than cm/s

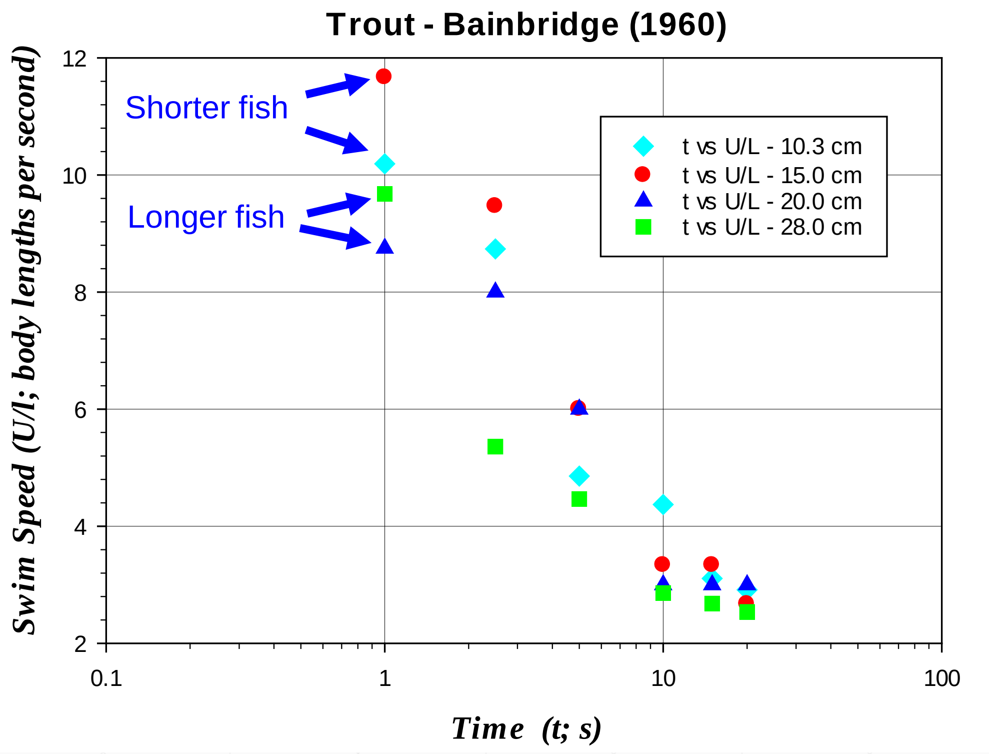
Expressing speed in BL/s (i.e. U/L) is still used in most studies to collapse size-related data.

BL/s has dimensions of 1/s

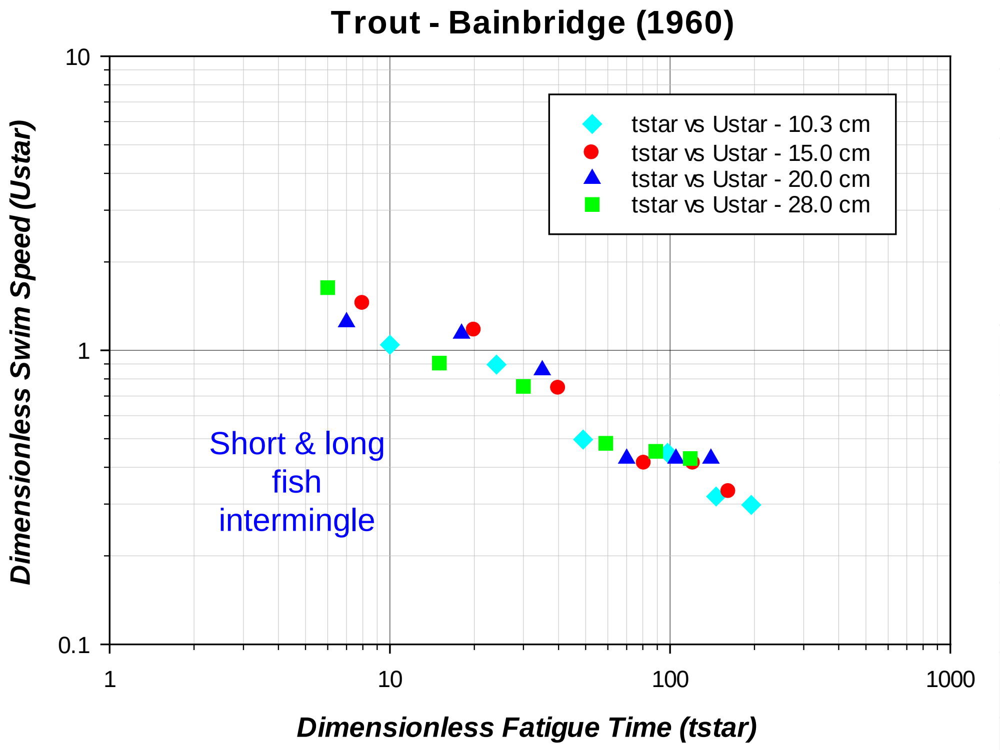
Webb 2006:

Remarkably, most of the variation in tail-beat patterns with speed, for three species (dace *Leuciscus leuciscus*, goldfish *Carassius auratus*, and trout *Salmo irideus=Oncorhynchus mykiss*) could be expressed in a single equation. Bainbridge's results shored up scattered observations suggesting larger fish achieve higher absolute speeds, but lower relative speeds expressed in BL/s.

Knotty problems of how to improve representation of scaling into a single **non-dimensional** scaling function have largely been ducked since.



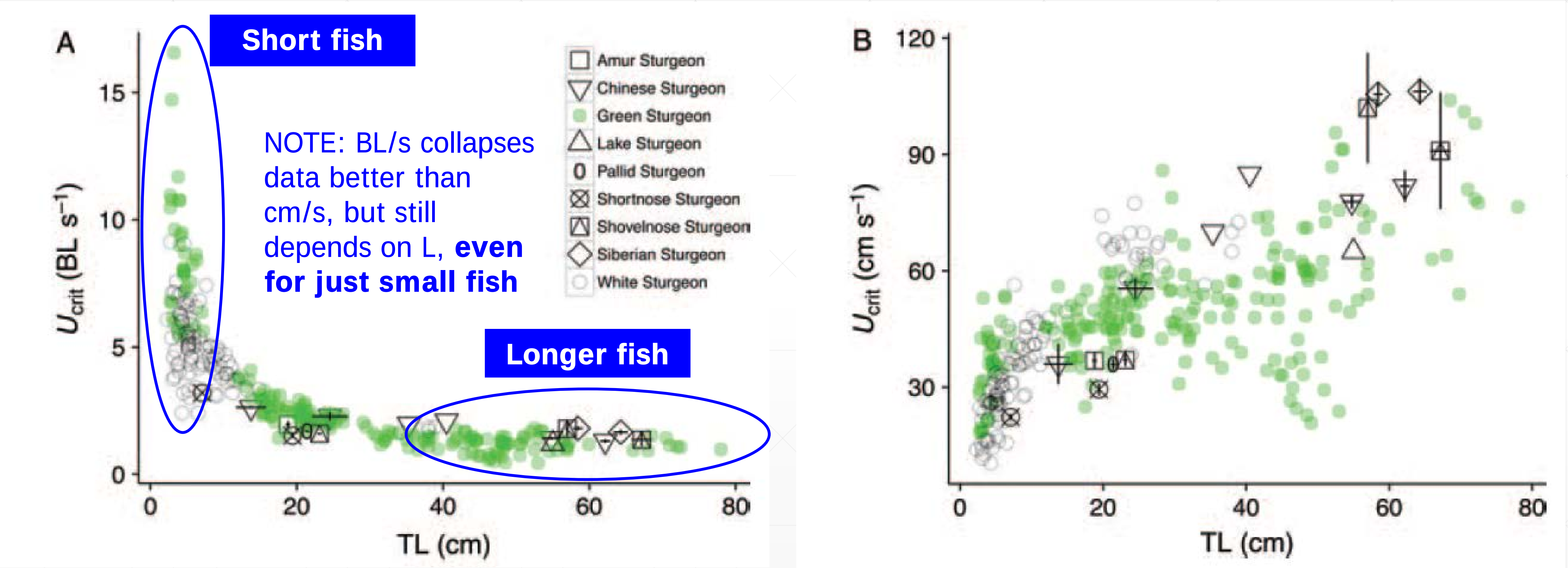
$$U_* = \frac{U}{\sqrt{gl}}$$



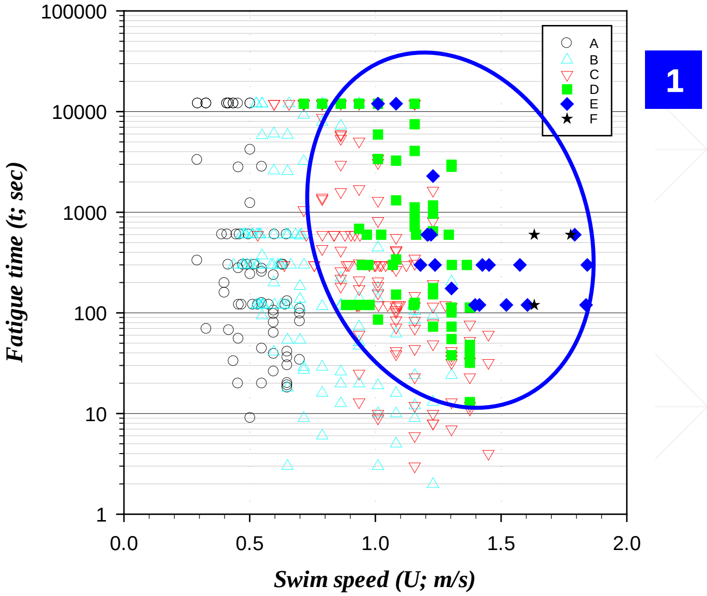
$$t_* = \frac{t}{\sqrt{l/g}}$$

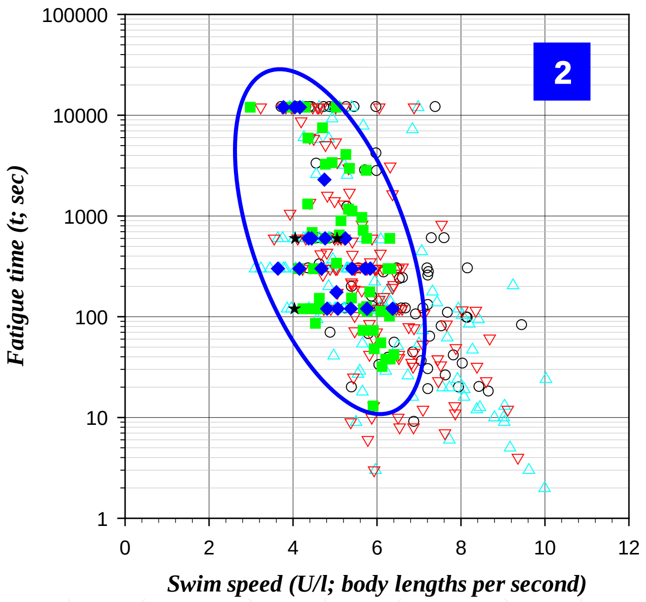
NOTE: Dimensionless parameters U_* and t_* collapse data better than BL/s (dimensions of 1/s). BL/s separates points by fish length; U_* and t_* bring together short and long fish.

Larval green and white sturgeon



Verhille, C.E., Poletto J.B., Cocherell, D.E., DeCourten, B., Baird, S., Cech, J.J. Jr., Fangue, N.A. 2014



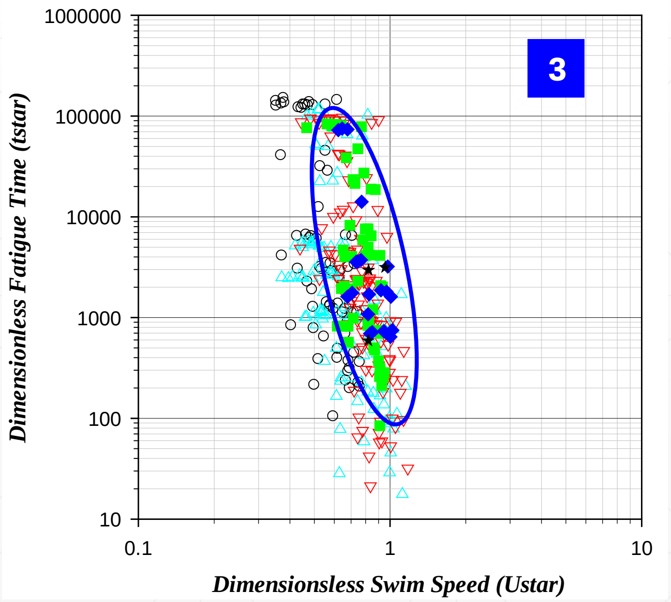


Brook trout

(*Salmo fontinalis*)

Peake et al. 1997

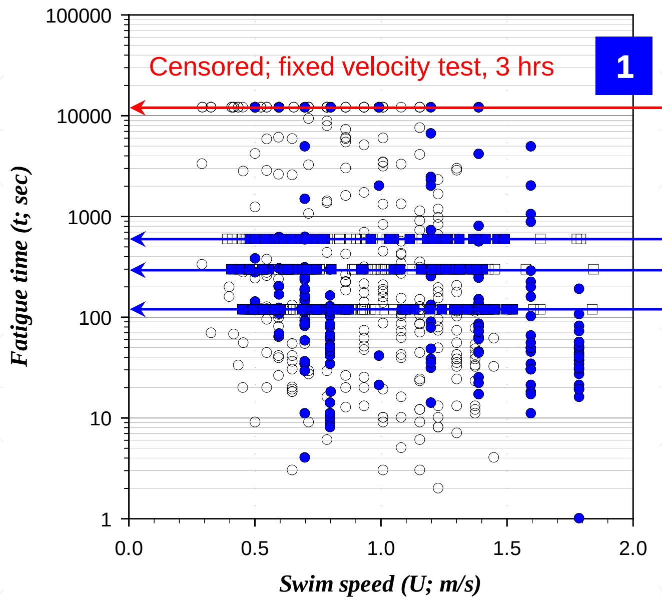
Filled symbols reflect longer fish > 200 mm and open symbols < 200 mm.

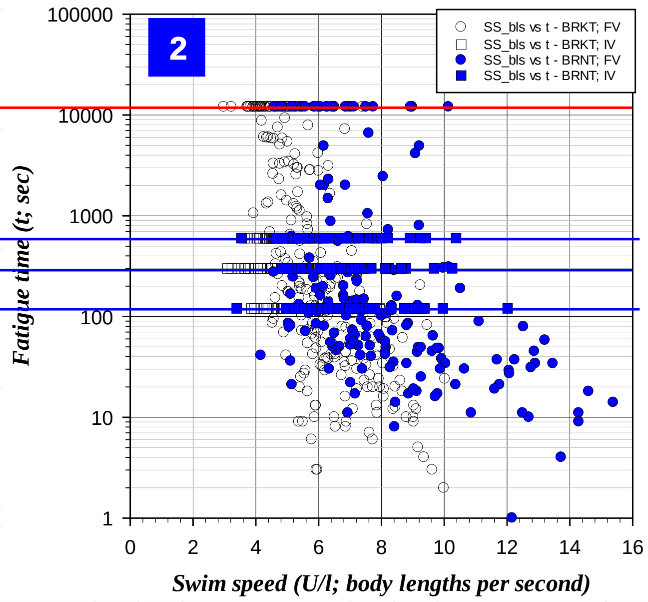


A: *50 < l (mm) <= 100*
B: *100 < l (mm) <= 150*
C: *150 < l (mm) <= 200*
D: *200 < l (mm) <= 250*
E: *250 < l (mm) <= 350*
F: *350 < l (mm) <= 450*

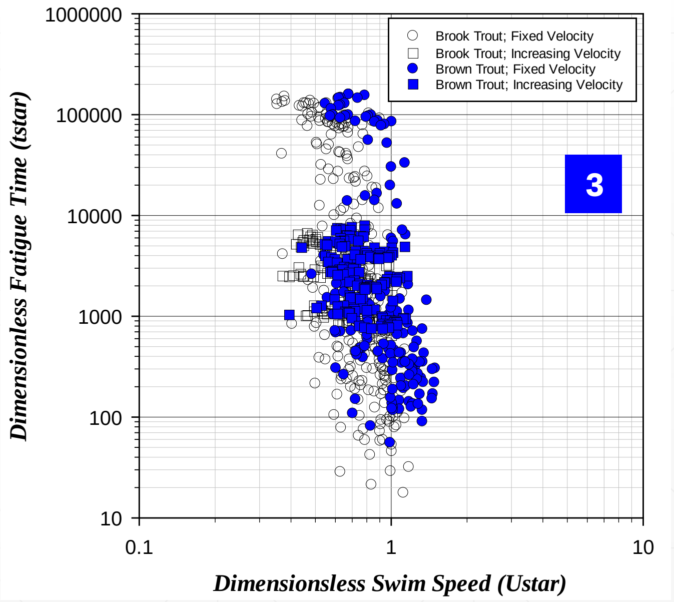
Longer fish:

- **widest scatter & shift to the right** when speeds in **m/s** — 1
- **wide scatter & shift to the left** when in **BL/s** — 2
- **least scatter; longer & shorter fish come together with U_* and t_*** — 3





Increasing velocity test with 10, 5 & 2 min increments



widest scatter with m/s 1

wide scatter with BL/s 2

least scatter with U_* and t_* 3

Brook & brown trout

Peake et al. 1997

Filled symbols are brown trout data and open symbols are brook trout, circles are fixed velocity test and squares are increasing velocity test.

3 With U_* and t_* both brook & brown trout overlap showing performance similarity.

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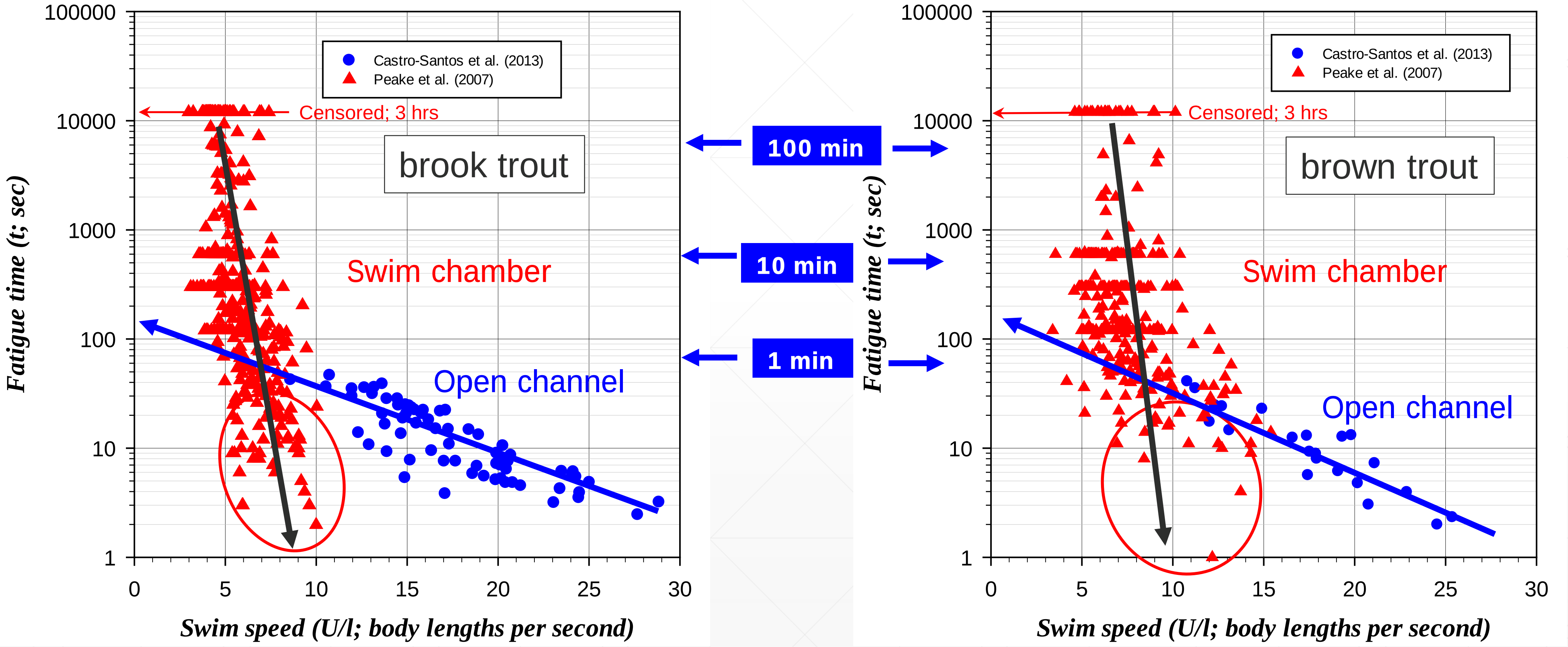
Complete fatigue curves –

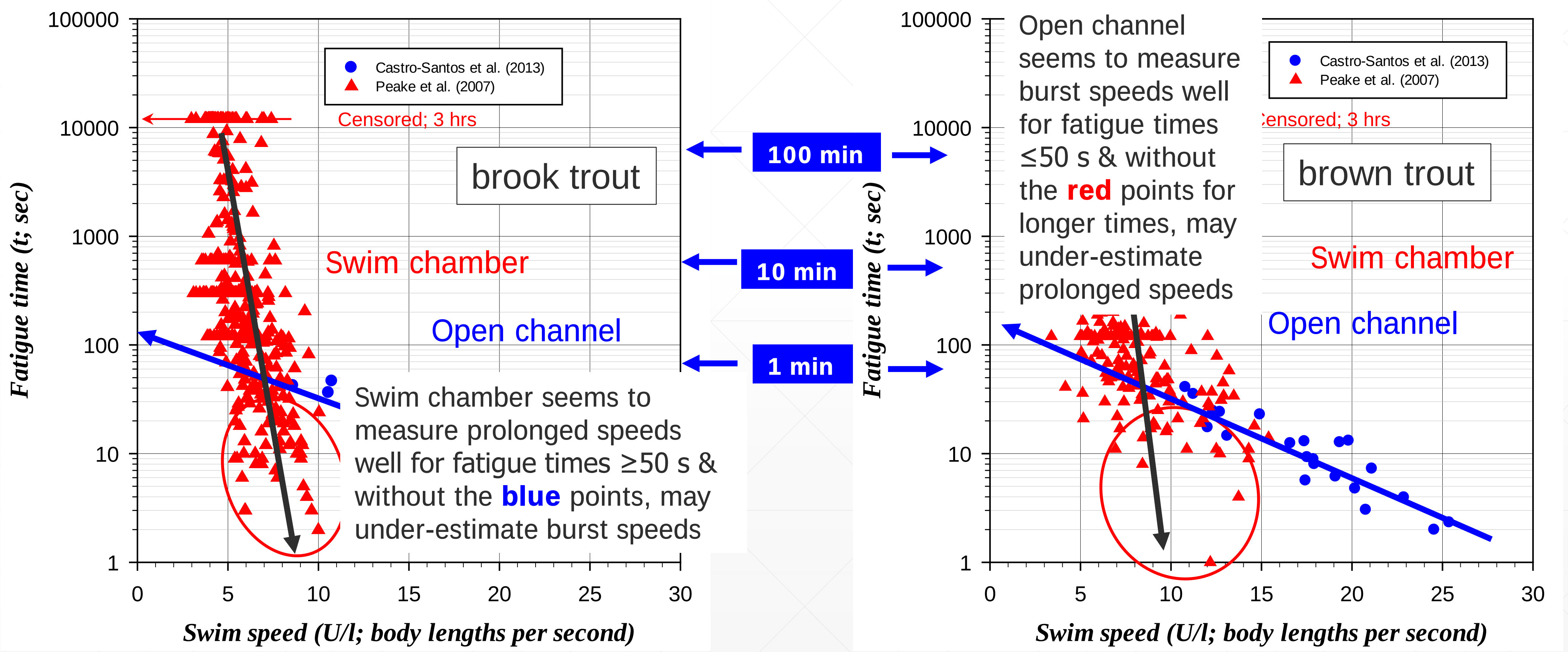
data from seconds to tens of minutes needed



NOTE: predictions based only on open channel data (**blue**) would under-estimate prolonged speeds, while predictions based only on swim chamber data (**red**) would under-estimate burst speeds. Both are needed to define a complete fatigue curve.

Complete fatigue curves –

data from seconds to tens of minutes needed



Salmon & Trout

Subcarangiform swimmers with burst & prolonged data

$U = U/l$ or BL/s

$$U_* = \frac{U}{\sqrt{gl}}$$

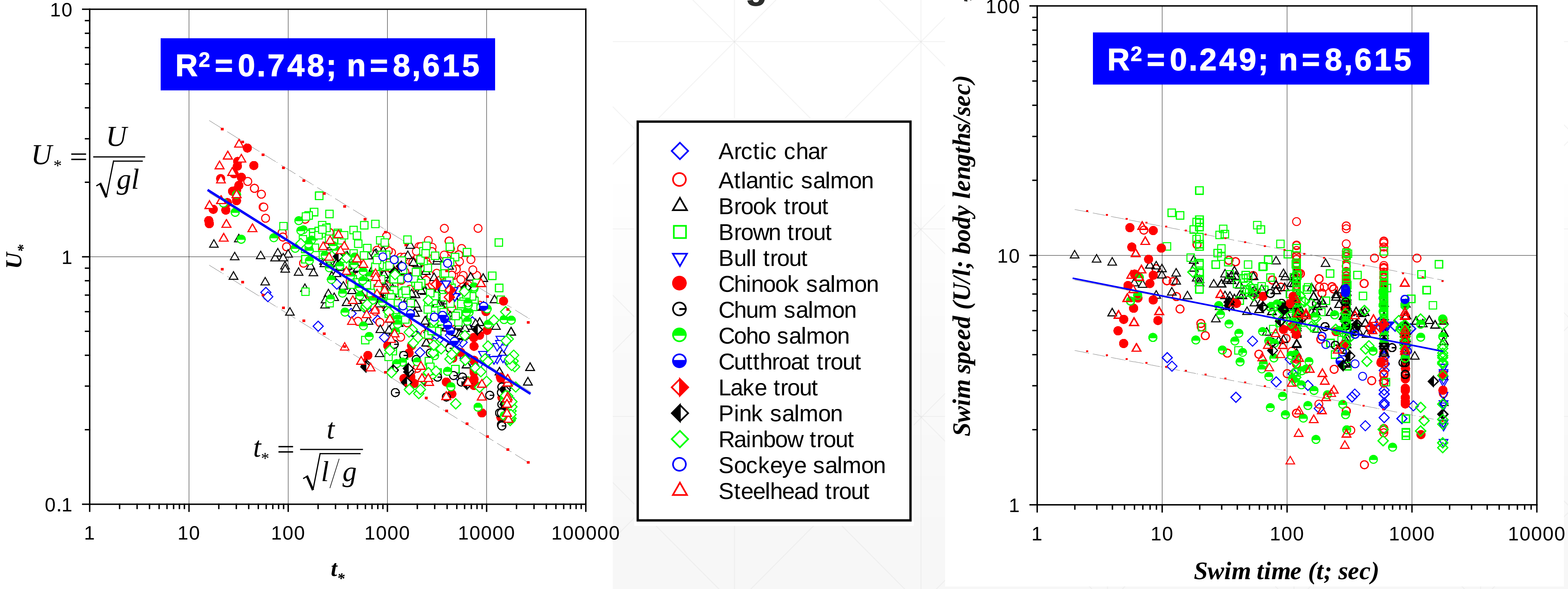
Species Groups	R^2	SEE	R^2	SEE	n
Steelhead trout	0.153	0.227	0.908	0.230	1,877
Steelhead and Rainbow trout (*Oncorhyncus mykiss*)	0.298	0.276	0.911	0.236	3,084
Oncorhyncus species	0.330	0.284	0.856	0.290	6,077
Salmon and Trout (Salmoninae)	0.249	0.332	0.748	0.343	8,615

The dimensionless fish speed U_*, which includes $\sqrt{l}$ as a scale, provides notably stronger regressions than traditional **BL/s** for both single species or groups of species of similar swimming performance, such as subcarangiform swimmer.

Dimensionless vs BL/s – Salmon & Trout

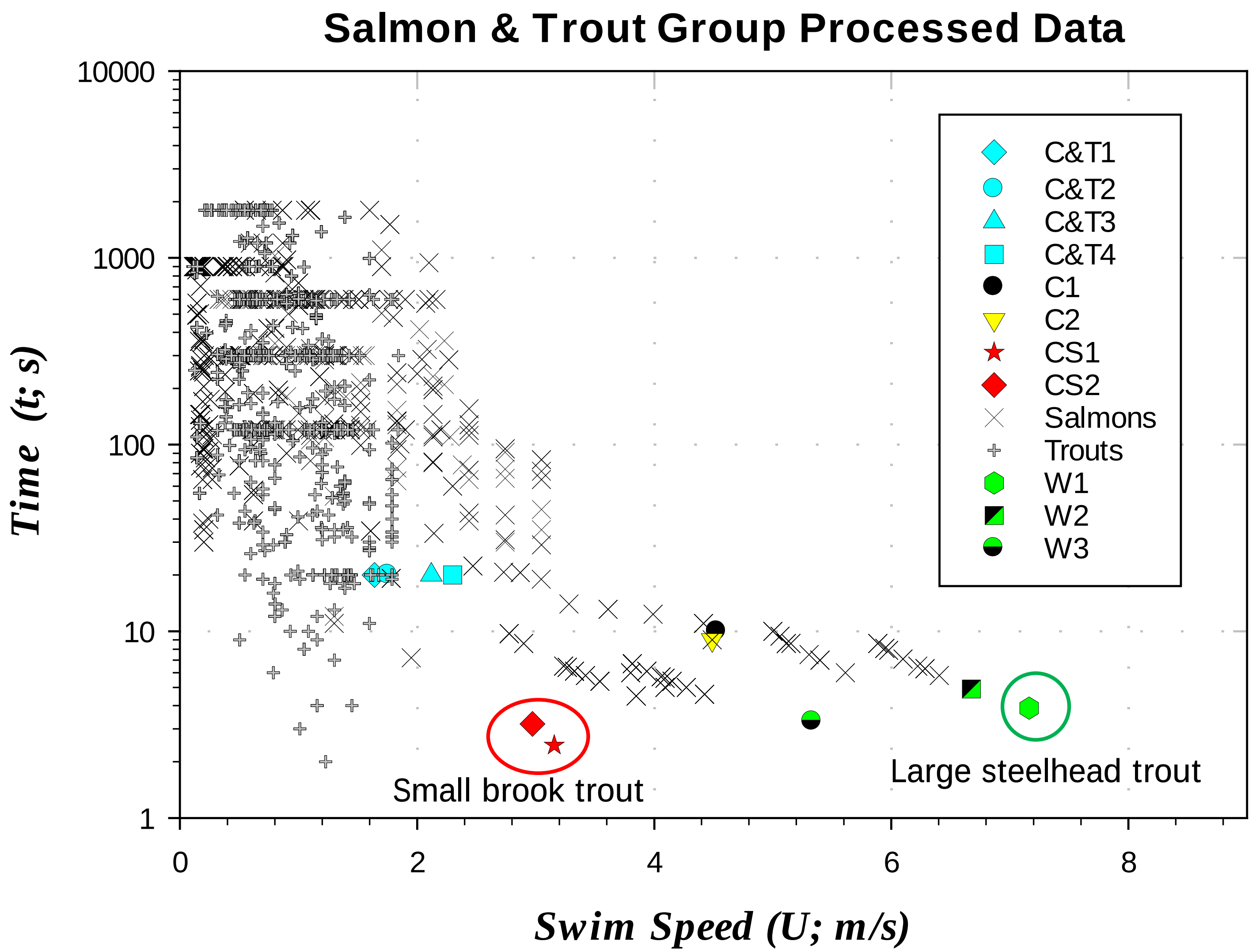
NOTE: Data with independent variable as x or y are included. Least square (black lines) & Dening (colour lines) regressions provide similar results (presented at Ecohydraulics 2012, Vienna).

R^2 66.7% higher with U_*



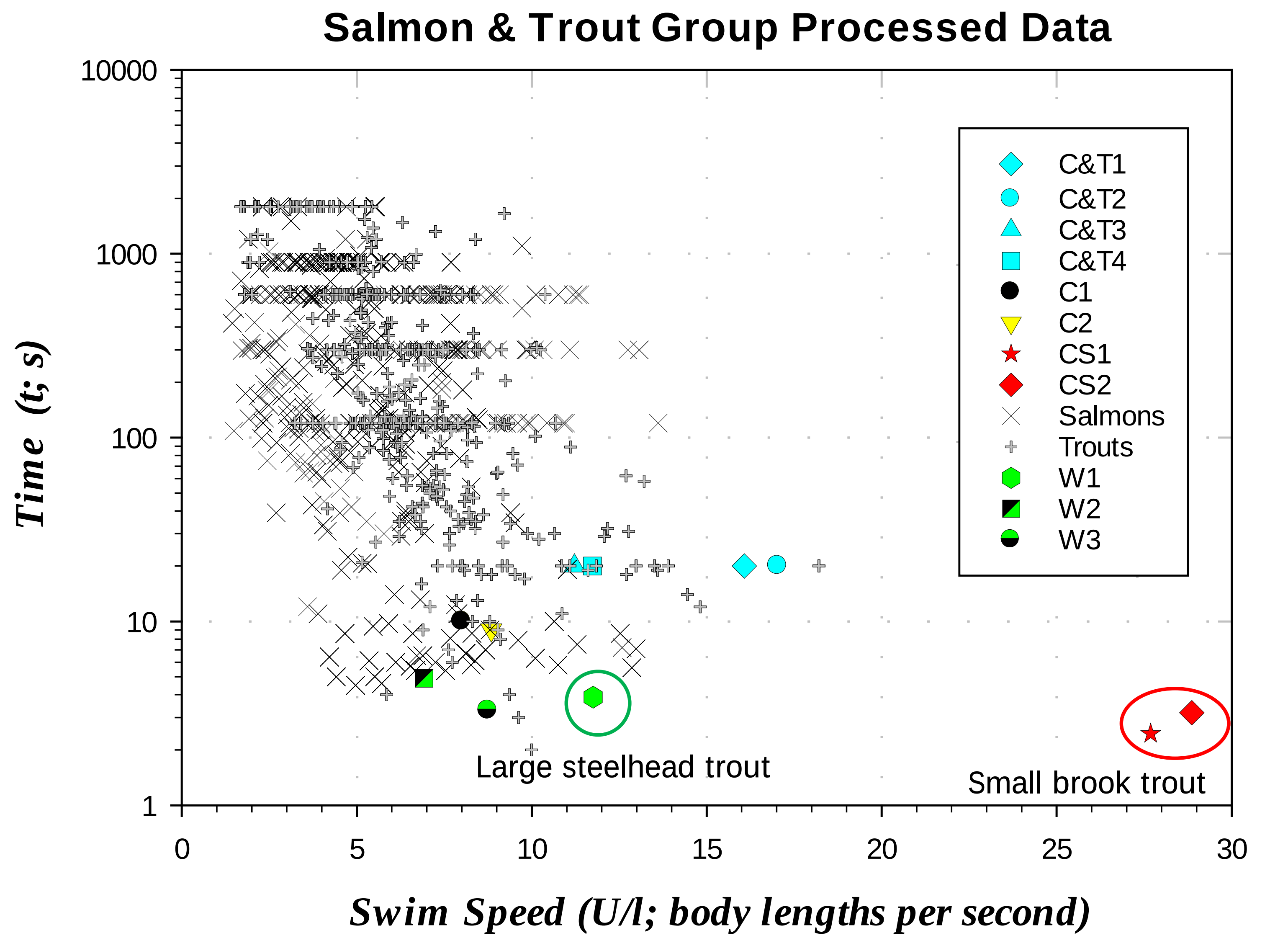
Summary table of data points

Dataset	Species	Reference	Length (l; m)	U (m/s)	Time (t; s)	U/l (BL/s)	Ustar	tstar	Appartus; Method
CS1	Brook trout	Castro-Santos et al. (2013)	0.114	3.16	2.45	27.69	2.985	22.7	Open channel; FV
CS2	Brook trout	Castro-Santos et al. (2013)	0.103	2.97	3.19	28.86	2.957	31.1	Open channel; FV
C&T1	Brown trout	Clough & Turnpenny (2000)	0.102	1.64	20	16.08	1.639	196.1	Stamina tunnel; IV
C&T2	Brown trout	Clough & Turnpenny (2000)	0.103	1.755	20	17.04	1.746	195.2	Stamina tunnel; IV
C&T3	Brown trout	Clough & Turnpenny (2000)	0.189	2.12	20	11.22	1.557	144.1	Stamina tunnel; IV
C&T4	Brown trout	Clough & Turnpenny (2000)	0.196	2.3	20	11.73	1.659	141.5	Stamina tunnel; IV
C1	Atlantic salmon	Colavecchia et al. (1997)	0.57	4.53	10.0	8.00	1.922	41.6	Open channel; FV
C2	Atlantic salmon	Colavecchia et al. (1997)	0.51	4.49	9.0	8.84	2.011	39.6	Open channel; FV
W1	Steelhead trout	Weaver (1963)	0.61	7.16	3.88	11.75	2.929	15.6	Open channel; FV
W2	Chinook salmon	Weaver (1963)	0.97	6.68	4.89	6.92	2.169	15.6	Open channel; FV
W3	Silver salmon	Weaver (1963)	0.61	5.33	3.28	8.75	2.181	13.2	Open channel; FV



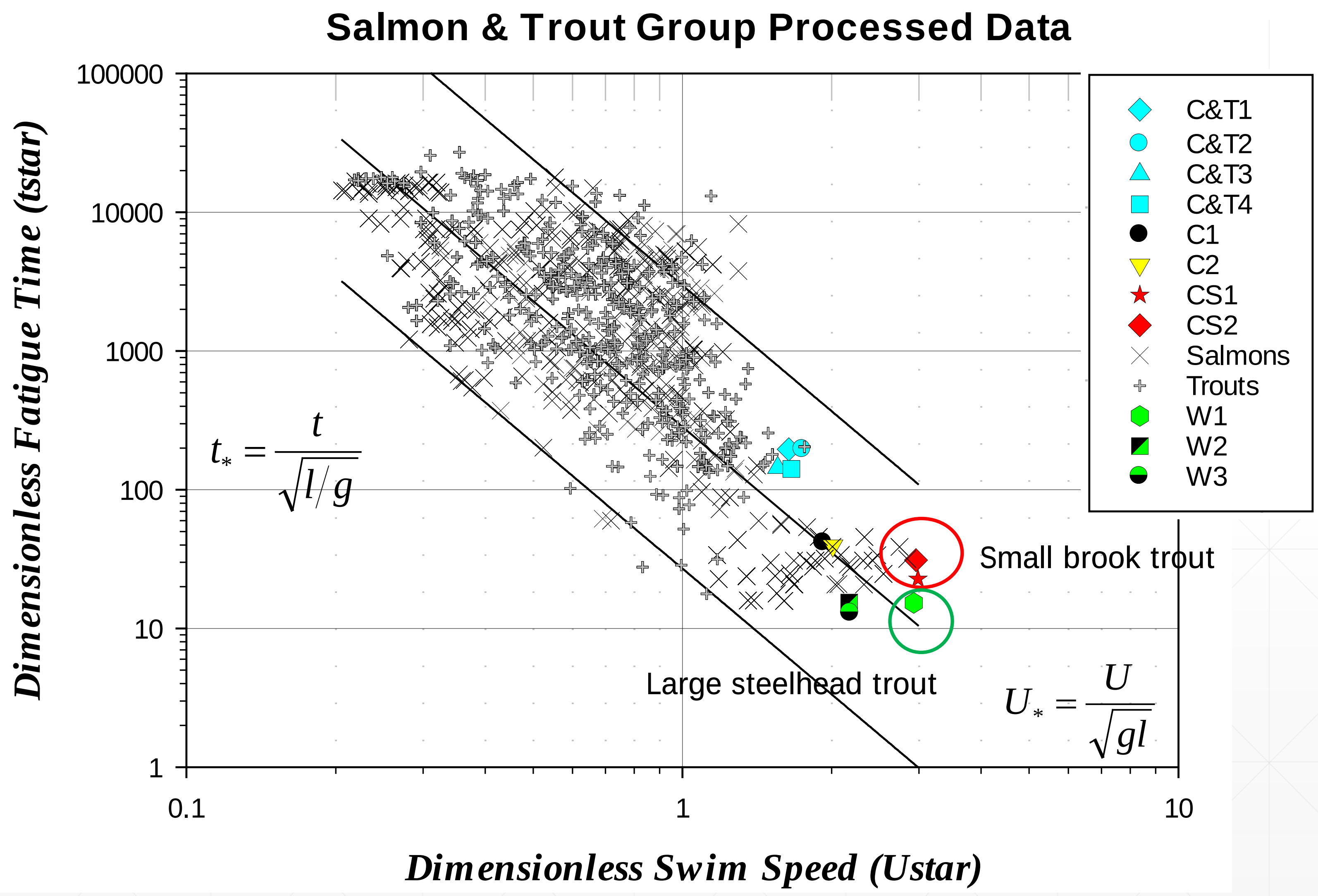
Fish separate based on length, since **longer** fish have **higher** speeds in **m/s** than shorter ones

NOTE: In m/s, the two small brook trout have much lower speed than the large steelhead, which is the fastest fish in this graph.



Fish separate based on length, since **longer** fish have **lower** speeds in BL/s than shorter ones.

NOTE: In BL/s, the two small brook trout seem so fast as to be breaking some “speed barrier”, while the large steelhead appears like a poor performer.



Dimensionless parameters improve scaling with fish length since **long** and **short** fish come together.

NOTE: The two small brook trout are just above average performers and close to the large steelhead.

Concluding remarks

- The commonly used dimensioned metric of BL/s is dependent on fish length and caution is needed in its use for predicting speeds for fish sizes larger or smaller than available data.

- The dimensionless speed U_* scales well with fish length and provides robust fatigue curve regressions for single or multiple species with similar swimming abilities.

- We are open to collaboration on meta-analyses of existing fish swimming performance data, including kinematics, and strategies on new research, taking advantage of the ecohydraulic approach which uses dimensionless parameters.

Thank you!

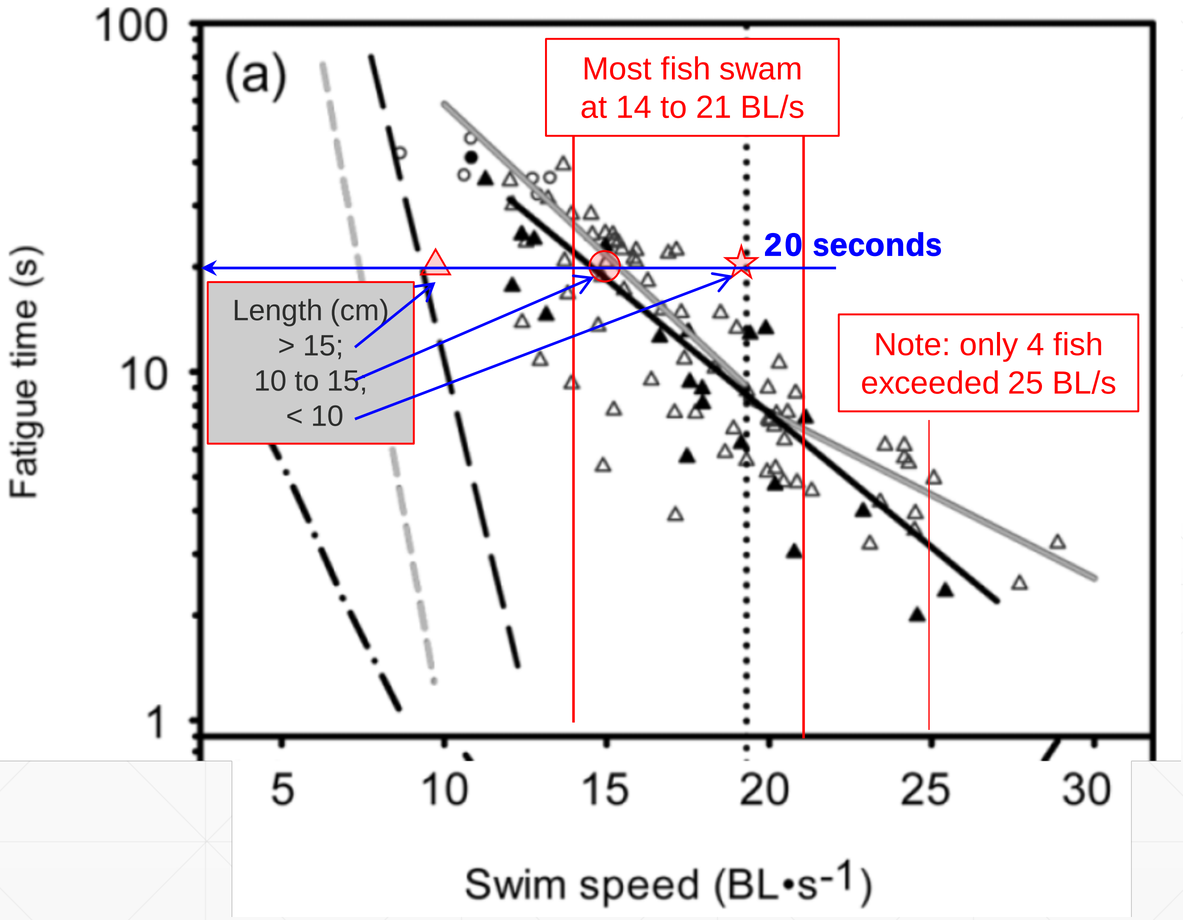


Fig. 5a. Swim speed – fatigue time relationship with data from Bainbridge (1960, sensu Brett 1964) for rainbow trout (dash-dot) and from Peake et al. (1997) for brook trout (short dashes) and brown trout (long dashes) for comparison.

NOTE: Fatigue time scale is for data ≤100 s, yet Peak et al. (1997) have data up to 10,000 s, i.e. the most useful prolonged speed data are neglected in this comparison (see slides 7 & 8) .

Brown Trout from Clough & Turnpenny 2000 (red symbols) increasing velocity swim tunnel test superimposed on Castro-Santos et al. 2003 data where the 20 second time step is used as endurance time and the critical swimming speed is swim speed. Data is relatively close fit, where the larger and smaller fish lengths from Clough & Turnpenny fall outside Castro-Santos et al. 2013 dataset and fish with a similar lengths have the best fit.

Data points in this figure were digitized and analysed to estimate the corresponding fish lengths for the highest swim speeds > 25 BL/s

Castro-Santos, Sanz-Ronda & J. Ruiz-Legazpi 2013.

References

Bainbridge, R. 1958. The speed of swimming of fish as related to size and to the frequency and the amplitude of the tail beat. J. Exp. Biol. 35, 109-133.
Bainbridge, R. 1960. Speed and stamina in three fish. J. Exp. Biol. 37, 129-153.
Castro-Santos, T. , Sanz-Ronda, F.J., Ruiz-Legazpi , J. 2013. Breaking the speed limit - comparative sprinting performance of brook trout (Salvelinus fontinalis) and brown trout (Salmo trutta). Can. J. Fish. Aquat. Sci. 70: 280–293 doi:10.1139/cjfas-2012-0186.
Clough, S.C., and Turnpenny, A.W.H. 2000. Swimming speeds in Fish: Phase 1. R&D Technical Report W2-026/TR1. Fawley Aquatic Research Laboratories LTD.
Colavecchia, M., C. Katopodis, R. Goosney, D.A. Scruton, and R.S. McKinley 1998. Measurement of burst swimming performance in wild Atlantic salmon (*Salmo salar* L.) using digital telemetry. Regulated Rivers: Res. Mgmt, 14: 41-51.
Colavecchia, M.V. 1997. The use of telemetry to assess high speed swimming and fishway performance in salmonids. Thesis (M.Sc.) University of Waterloo. Waterloo, ON. 110 p.
Peake, S., McKinley, R.S., and Scruton, D.A. 1997. Swimming performance of various freshwater Newfoundland salmonids relative to habitat selection and fishway design. J. Fish Biol. 51: 719-723.
Peake, S. 1997. Personal communication Brook and Brown trout raw data.
Verhille, C.E., Poletto, J.B., Cocherell, D.E., DeCourten, B., Baird, S., Cech, J.J. Jr., and Fangue, N.A. 2014. Larval green and white sturgeon swimming performance in relation to water diversion flows. Conservation Physiology 2, doi:10.1093/conphys/cou031.
Webb P. 2006. Bainbridge sets the stage on scaling in fish swimming. J. Exp. Biol. 209, 1789-90.
Weaver, C.R. 1963. Influence of water velocity upon orientation and performance of adult migrating salmonids. U.S. Natl. Mar. Fish. Serv. Fish. Bull. 63: 97-121.