Biomechanical and ecological approaches to fit fish: Towards sustainable use of fish white muscle as meat.

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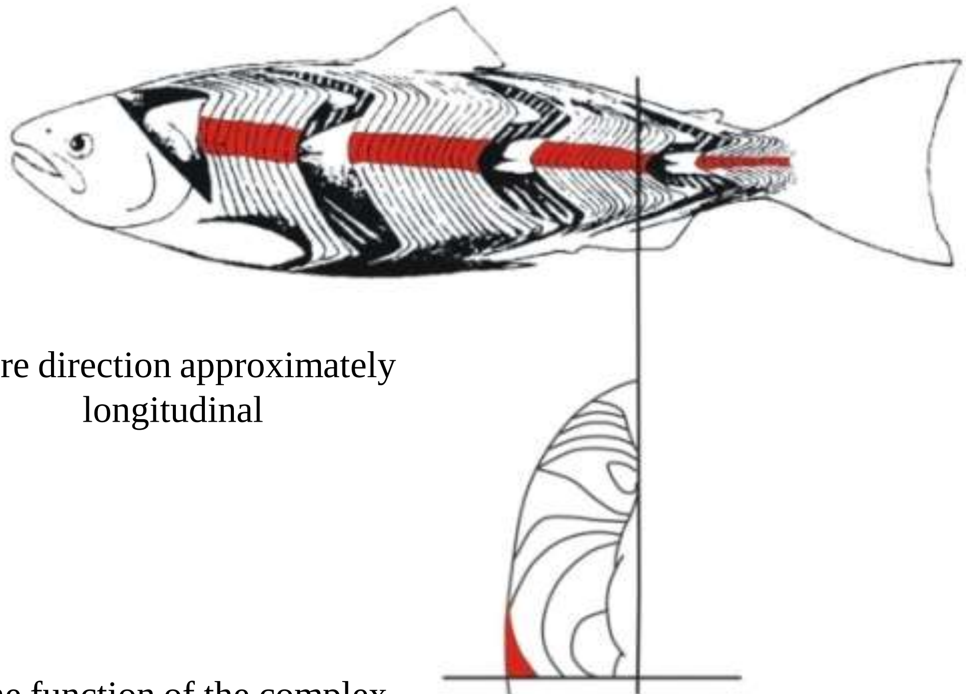
Fish red and white muscles

Myotomes and myosepts in adults



Fibre direction approximately longitudinal

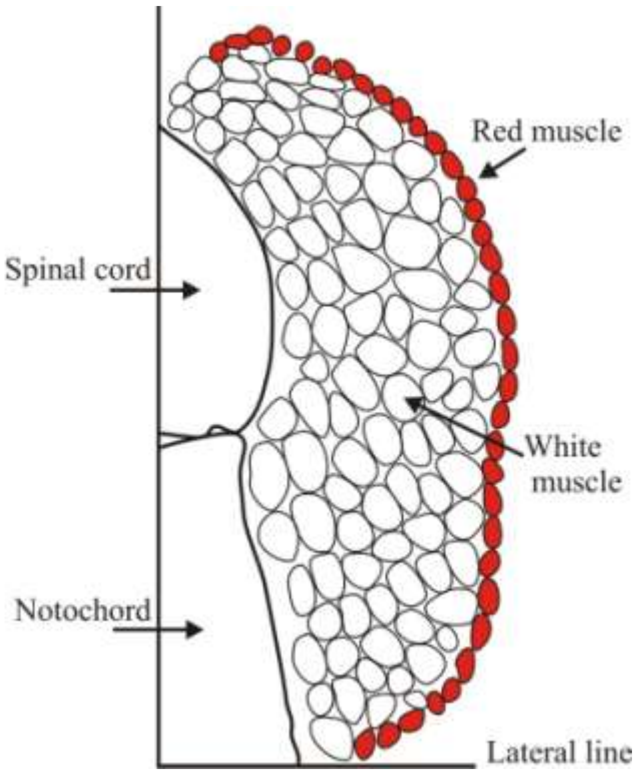
The function of the complex arrangement is still not clear.

Properties of red muscle:
- slow contractions
- virtually inexhaustible
- aerobic metabolism
- extensive blood supply
- large amounts of myoglobin
- high concentrations of large mitochondria
- high metabolism
- lactic acid is removed quickly

Properties of white muscle:
- fast
- exhaust quickly
- anaerobic metabolic pathways
- poor vascularisation
- lack of myoglobin
- few small mitochondria
- slow metabolism
- lactic acid removal takes hours

Why do white muscles taste better than red muscles?

The ontogeny of white muscle fibres



Larval carp muscle arrangement at first feeding

Embryonic stage:
Fibre numbers depend on temperature and oxygen levels.
But, the relationships differ among species. (Johnston, 2006)

After hatching, myogenesis continues:
Numbers and size increase.

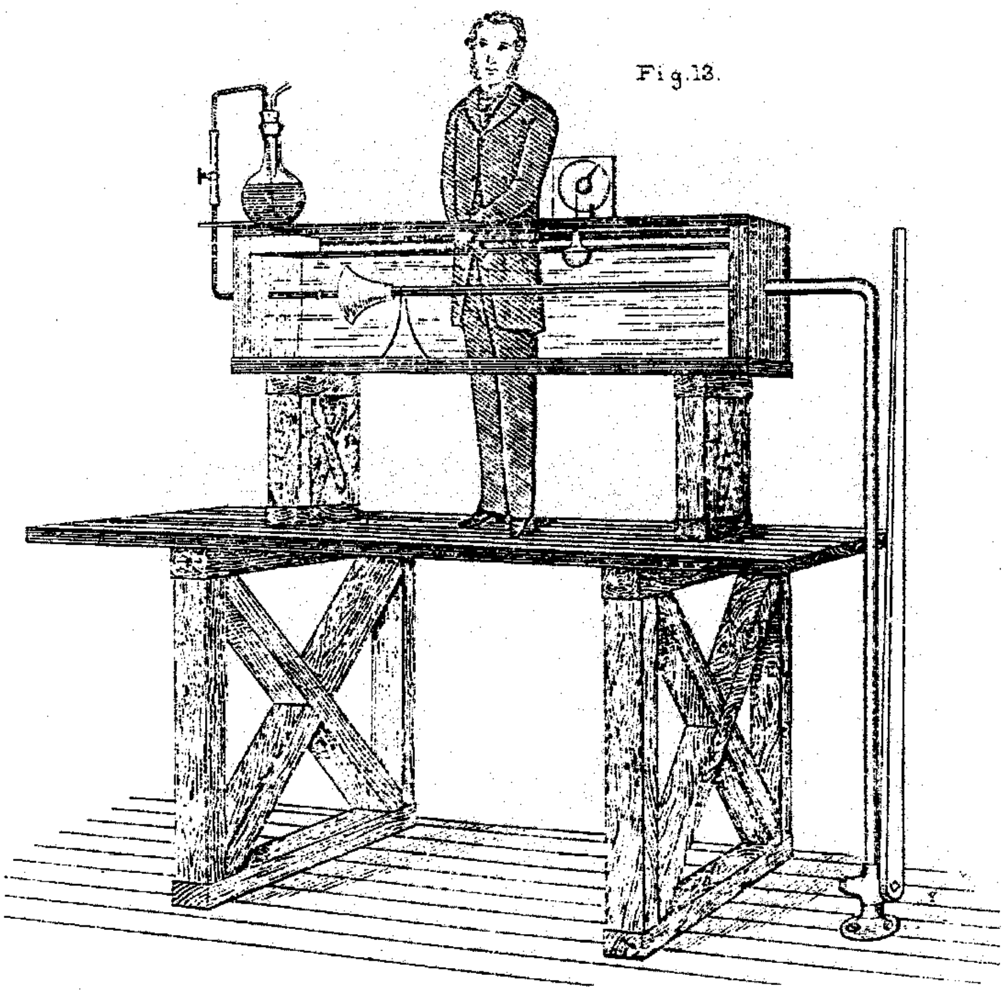
Carp larvae:
•The highest growth rates were shown by larvae fed with zooplankton.
•During the first 2 weeks of feeding the volume of trunk muscles increased more than 30-fold.
•Hyperplasia was responsible for 64% of this growth and hypertrophy for 36% .
(Alami-Durante, 1997)

Bold statement:
Larval stages determine to a large extend the white muscle mass of adults

What about the influence of swimming ?

Osborn Reynolds 1883:

An experimental investigation of the circumstances which determine whether the motion of water shall be direct or sinuous, and of the law of resistance in parallel channels.

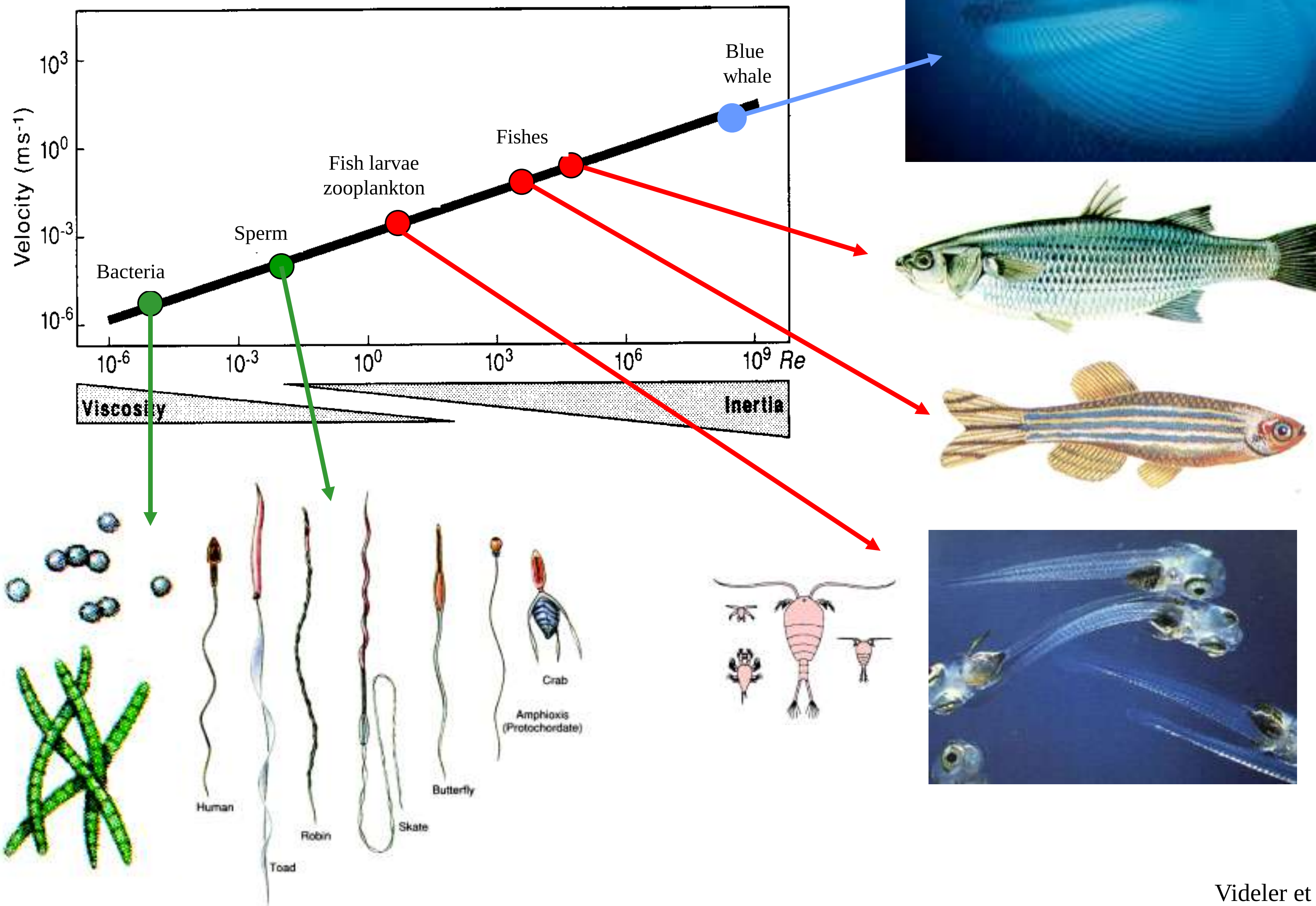


$$Re = u\, l\, \rho\, \mu^{-1} \quad (-)$$

u = velocity ($m\ s^{-1}$)
l = length (m)
ρ = density ($kg\ m^{-3}$)
μ = viscosity (Pas or Nsm^{-2})

Flow regimes of swimming organisms

Reynolds number



Videler et al. 2002

Scale effects

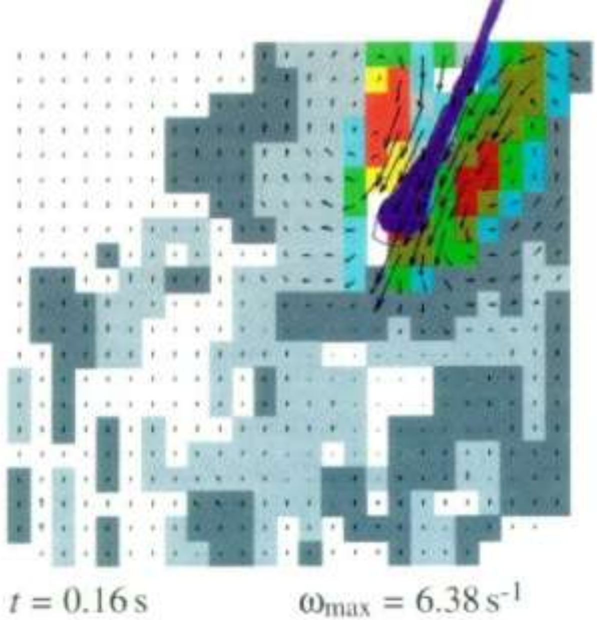
Swimming, feeding and escape reactions of copepods and fish larvae ($0.1 < Re < 100$)
Viscosity dominated

Burst swimming and coasting in juveniles and the adults of small fish ($160 < Re < 6000$)

Swimming in adult fish is inertia dominated

Swimming mullet:
$Re = 2 \times 10^4$

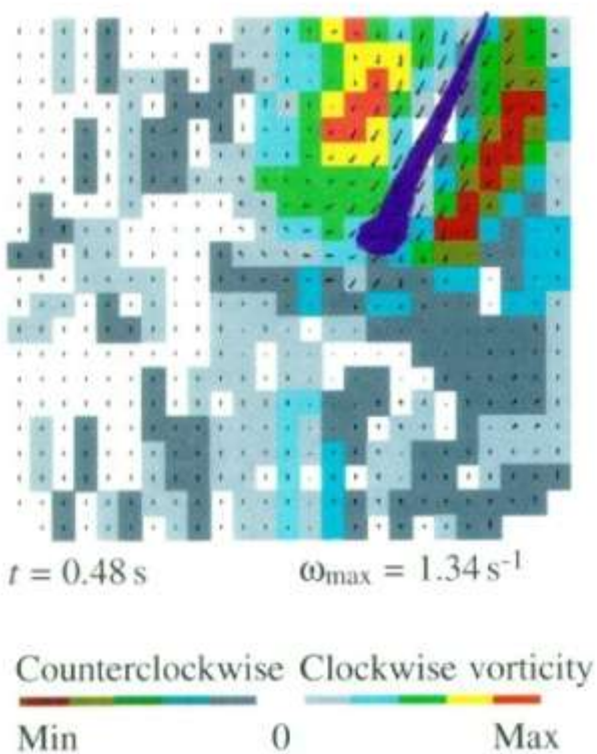
Coasting fish larvae and adults



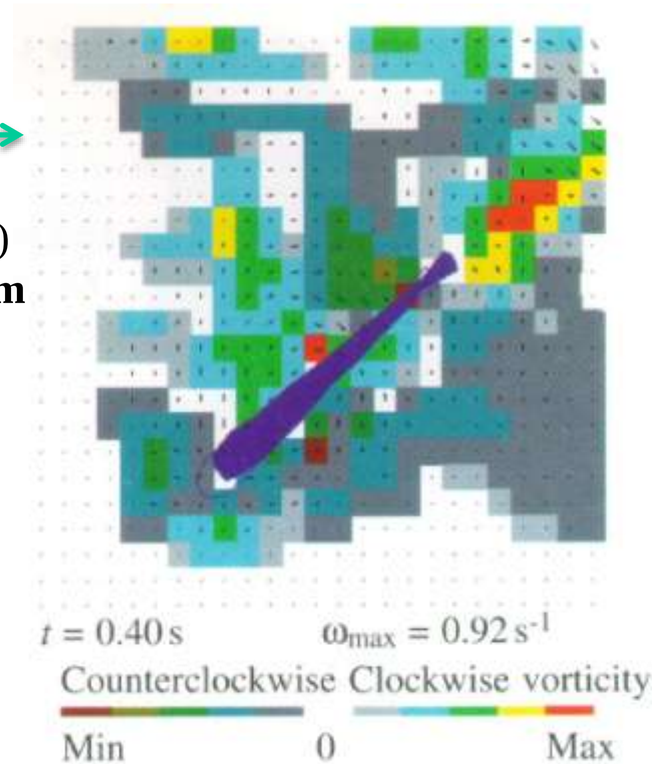
Velocities (arrows) and vorticity (colour coding) around a coasting ,**4.1 mm zebra danio larva**
Open outline is 0.04 s after filled outline

(Müller et al. 1997)

	Larva	Adult
Body length (mm)	4.1	35
Initial velocity (mm s^{-1})	40	120
Initial Re number	**160**	**4500**
Half initial speed after (s)	0.06	0.2
Distance covered to half speed (mm)	2.6	17



Velocities (arrows) and vorticity (colour coding) around a coasting **35 mm adult zebra danio**.
Open outline is 0.04 s after filled outline

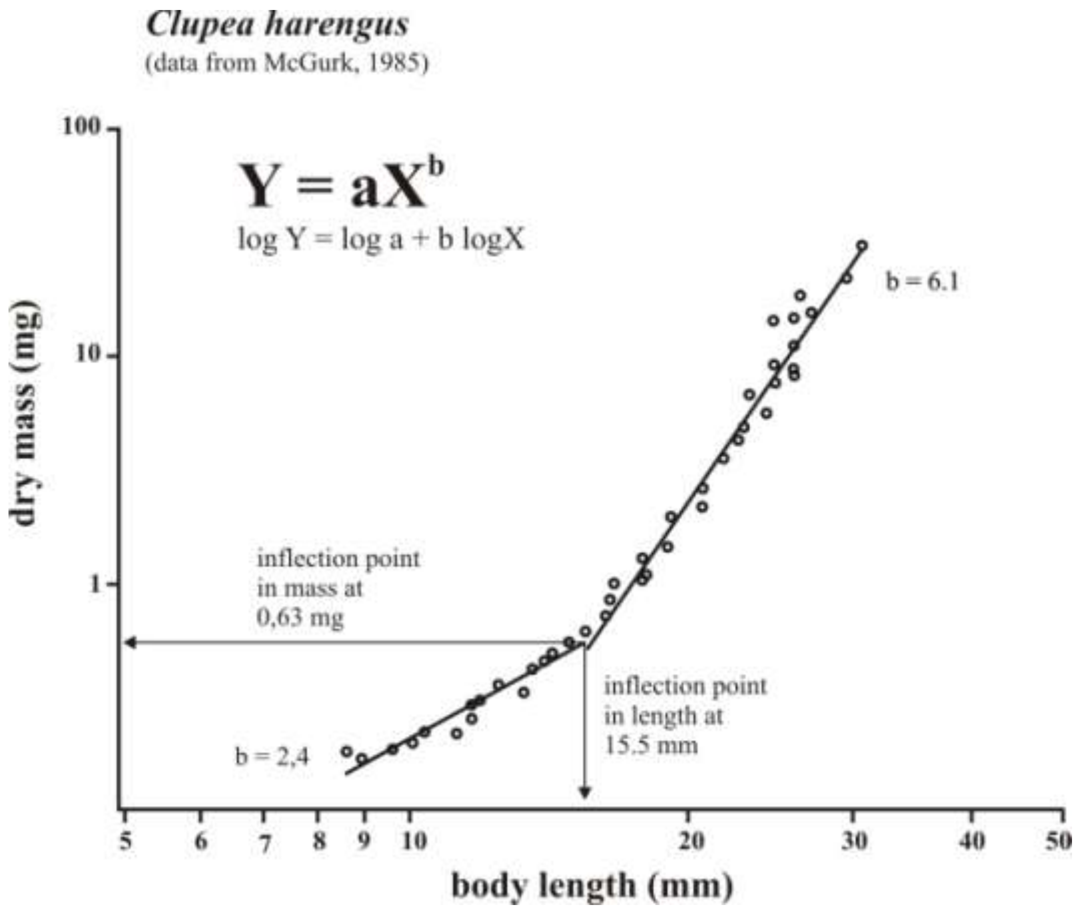


Burst and coast swimming in zebra fish larvae and adults

(Müller et al. 1997)

	Larvae	Adults
Body length (mm)	4	35
Maximum velocity (mm s^{-1})	16	130
Maximum velocity (L s^{-1})	4	3.7
Mean acceleration (mm s^{-2})	206	1623
Active distance (mm)	**1**	**8**
Resting distance (mm)	**1**	**30**
Active duration (s)	0.08	0.14
Resting duration (s)	0.92	0.86

The ecology of larval swimming



Larvae can escape the viscous regime and more predators by increasing in length and by swimming faster.

(Müller and Videler, 1996)

The ecology of larval swimming

Small fish larvae experience mortalities close to those of eggs.
Oxygen uptake is restricted.
Swimming performance is poor.
Size and speed make them prey for many predators.

Plaice larvae: 96 % expire the first month;
only 8 hatchlings out of 100 000 eggs survive the first year.
The mortality drops drastically as the larvae grow and swimming performance improves.

Temperature affects larval growth:
larvae of the fire clownfish (*Amphiprion melanopus*)
raised in 25 instead of 28 °C
had longer larval durations,
reduced growth rates and
were slower swimmers.
(Green & Fisher, 2004)

The ecology of larval swimming

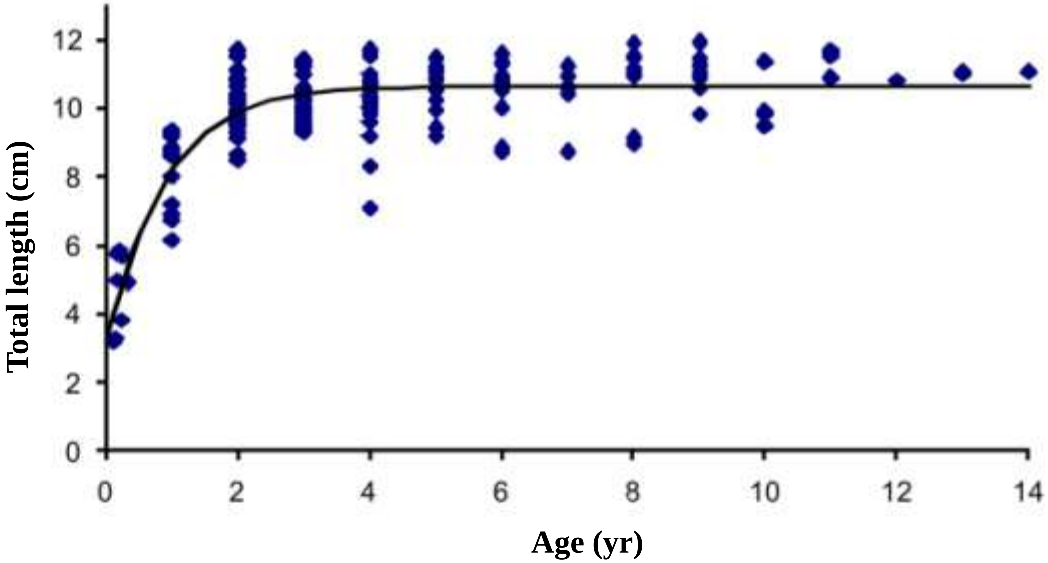
Muscles of **fast** growing carp larvae have a smaller cross sectional area with **more and thinner** fibres than larvae growing slower on a different **diet**.
(Alami-Durante et al., 1997)

Survival is determined by growth speed:
Faster growing individuals of bluefish (*Pomatomus saltatrix*) larvae have a higher survival probability.
(Hare & Cowen, 1997)

Selective mortality in the clupeid *Spratelloides gracilis* removes small, slow growing larvae.
The size of larvae was principally determined by egg size.
There is no selective mortality during the postlarval stages.
(Meekan et al. 2006)

Mortality is linked to condition:
The fastest swimmers among recruits of the bluehead wrasse (*Thalassoma bifasciatum*) grow faster and have a shorter vulnerable pelagic life phase.
(Grorud-Colvert & Sponaugle, 2006)

The ecology of larval swimming



The brownface butterfly fish, southern Red Sea

As a reaction to predator pressure :
Growth curves of many fish species show fast increase in length during the juvenile phase.
(Zekeria et al., 2006)

The presence of predators enhances growth!

Artificial natural selection

How can we use biological facts to improve fish culture?

In summary:

Natural selection processes work through increased predation on the smaller and least mobile individuals.
Small eggs, larvae and juveniles are consumed in large quantities.
Predators often include larger stages of the same species.
A few survivors reach adulthood to form the next breeding stock.

These survivors have the desired white muscle quality.

Hence:

Fish farming could use artificial natural selection to obtain the same goal.

Each species requires a specific approach based on its habits in the wild.

Conclusion: Fish culture can benefit from natural history.