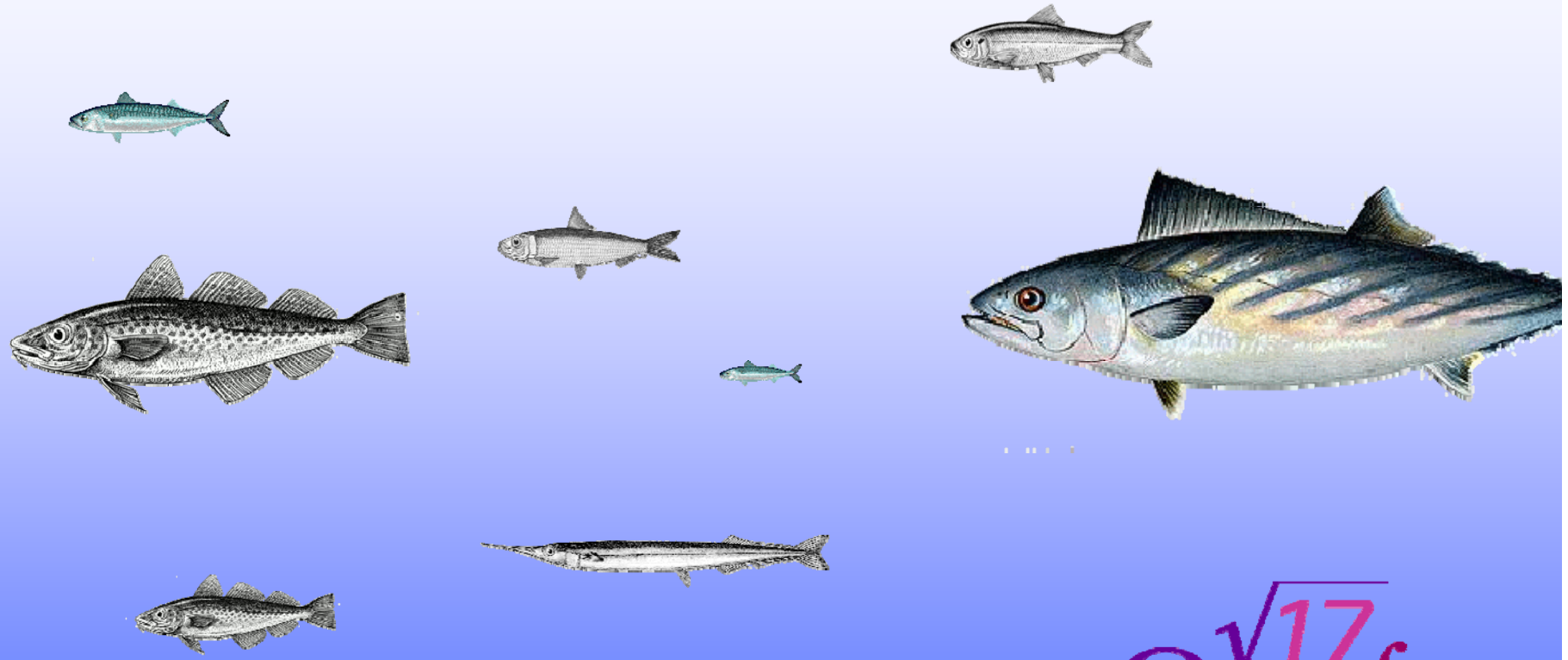
Size- and trait-based modelling of fish communities



Ken H. Andersen, Center for Ocean Life

$$M2_i = \frac{\sum_j \frac{dR}{dt} N_j \frac{\varphi_{ji}}{\varphi_j}}{N_i \omega_i}$$

$$\Delta \int_a^b \varepsilon \Theta^{\sqrt{17}} + \Omega \int \delta e^{i\pi} = \{2.718281828$$

Why?

Feeding the globe

Stocks are overexploited

Fish are valuable

http://news.bbc.co.uk

1 February 2011 Last updated at 16:02 GMT

Global fish consumption hits record high

By Mark Kinver
Science and environment reporter, BBC News

The global consumption of fish has hit a record high, reaching an average of 17kg per person, a UN report has shown.

Fisheries and aquaculture supplied the world with about 145m tonnes in 2009, providing about 16% of the population's animal protein intake.

The **findings published by the Food and Agriculture Organization** (FAO) also stressed that the status of global fish stocks had not improved.

It said that about 32% were overexploited, depleted or recovering.

"That there has been no improvement in the status of stocks is a matter of great concern," said Richard Grainger, one of the report's authors and FAO senior fish expert.

Fish products provide the planet's population with almost 16% of its animal protein intake

"The percentage of overexploitation needs to go down, although at least we seem to reaching a plateau," he observed.

The authors added that it was estimated that the level of overexploitation had increased slightly since 2006, but 15% of the stocks monitored by the FAO were either "underexploited" or "moderately exploited".

This meant that catches in these regions could increase in order to meet the demand for fish products.

Big business

The report also showed that fish continued to be the most-traded food commodity, worth US $102bn (£63bn) in 2008 - a nine percent increase

Related Stories

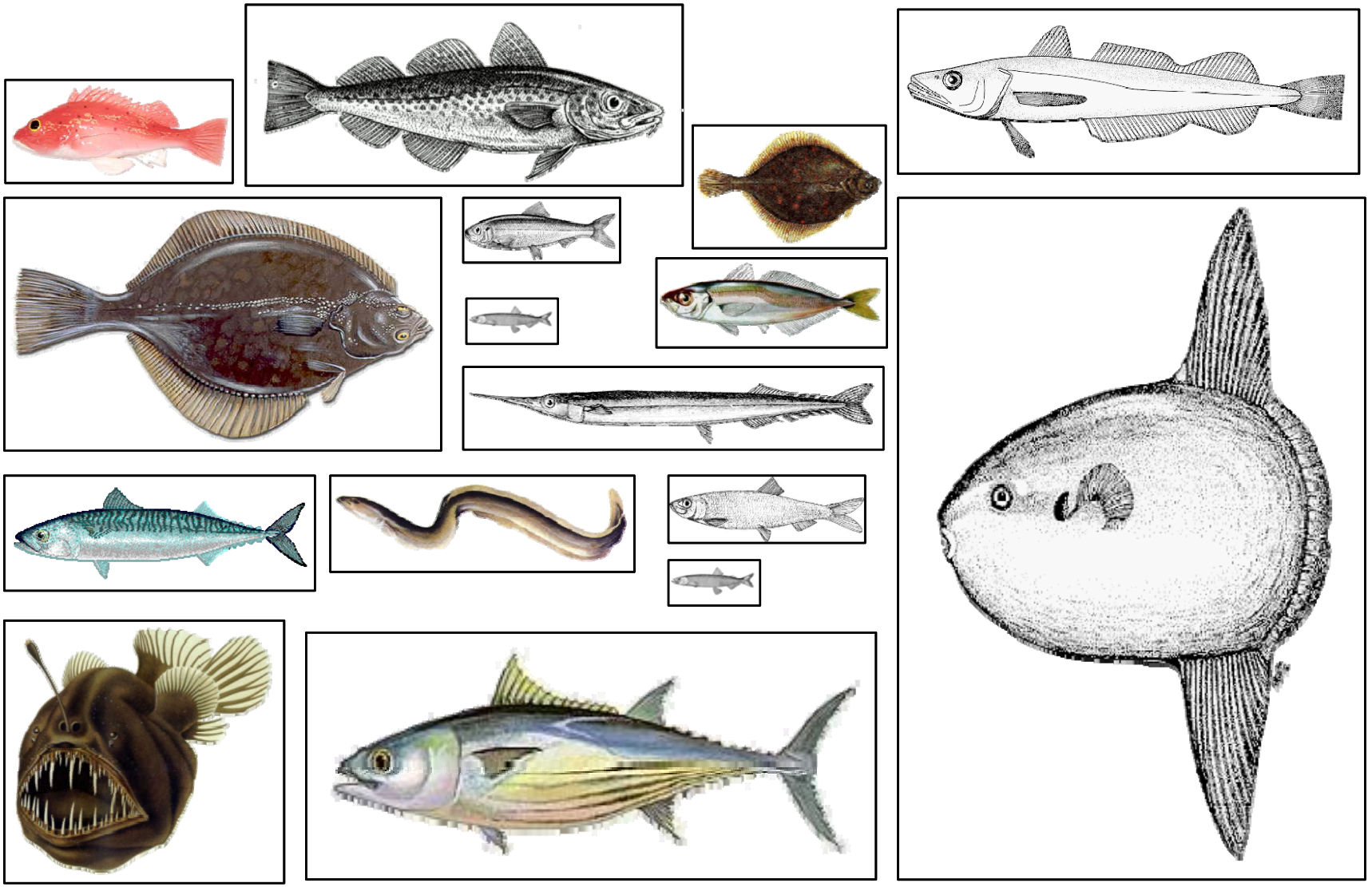
City street to open sea - fish farming's new frontiers

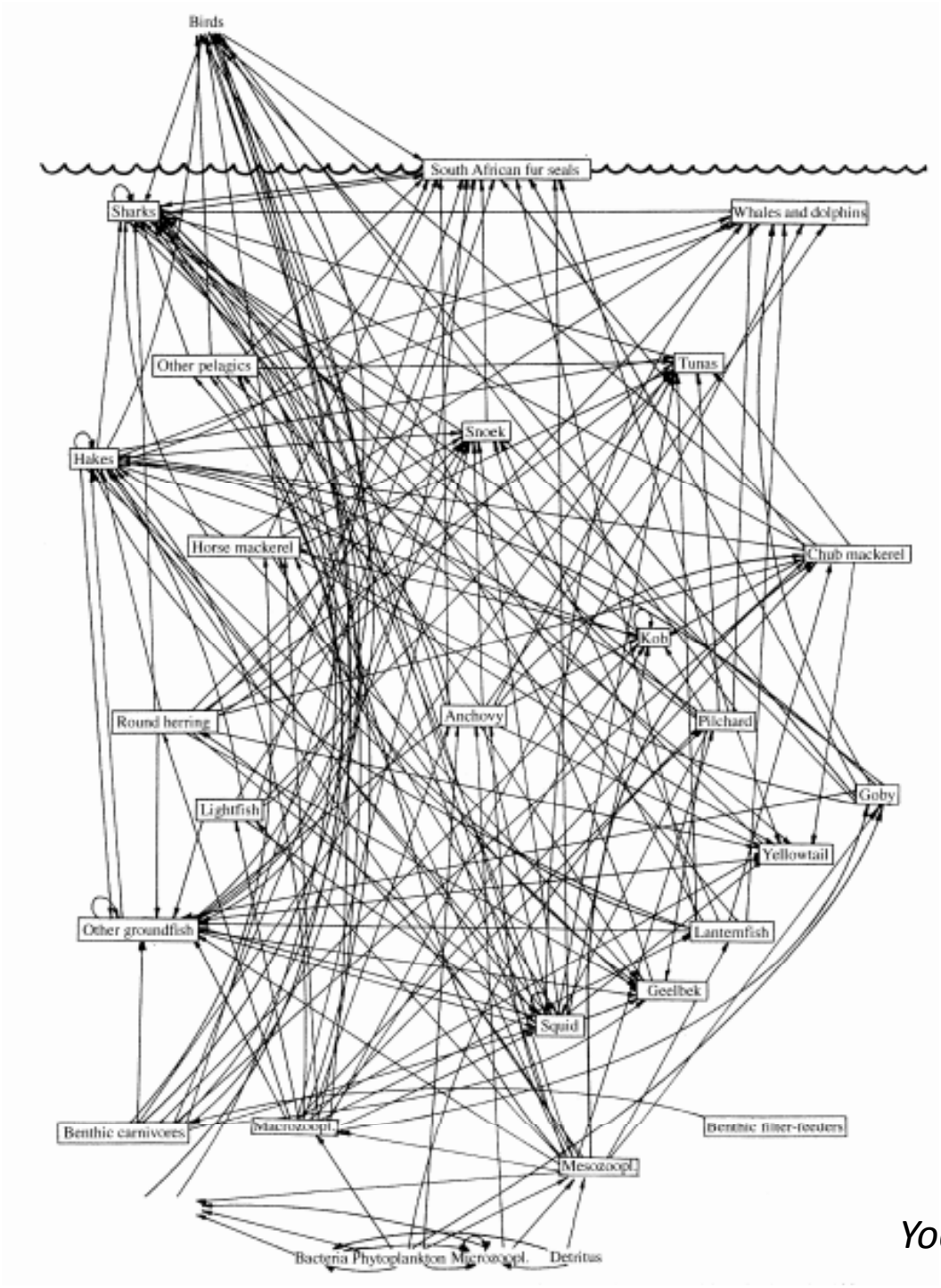
Vital role for 'neglected' fish

Ports 'fail on illegal fishing'

How?

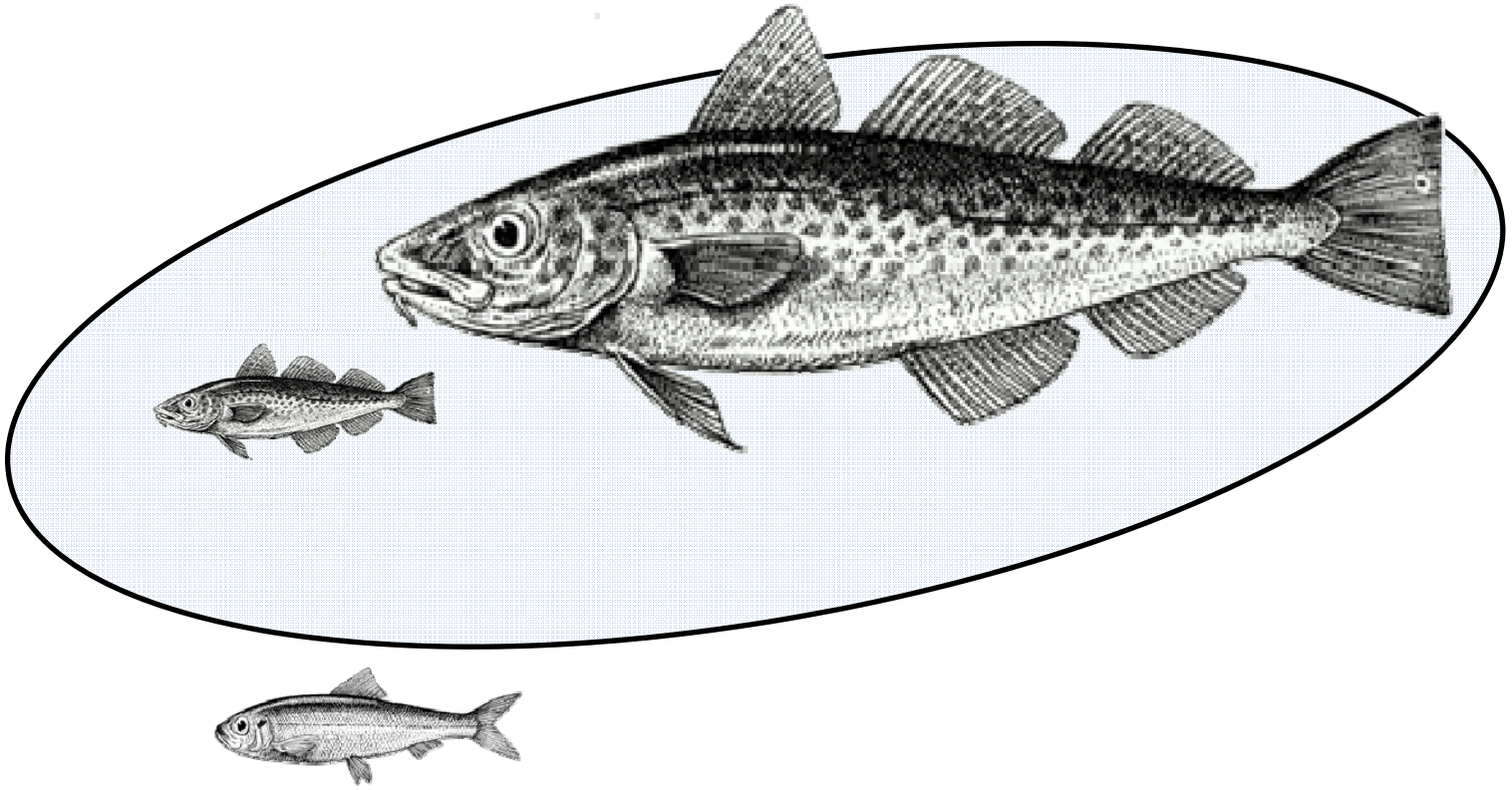
Fish traits



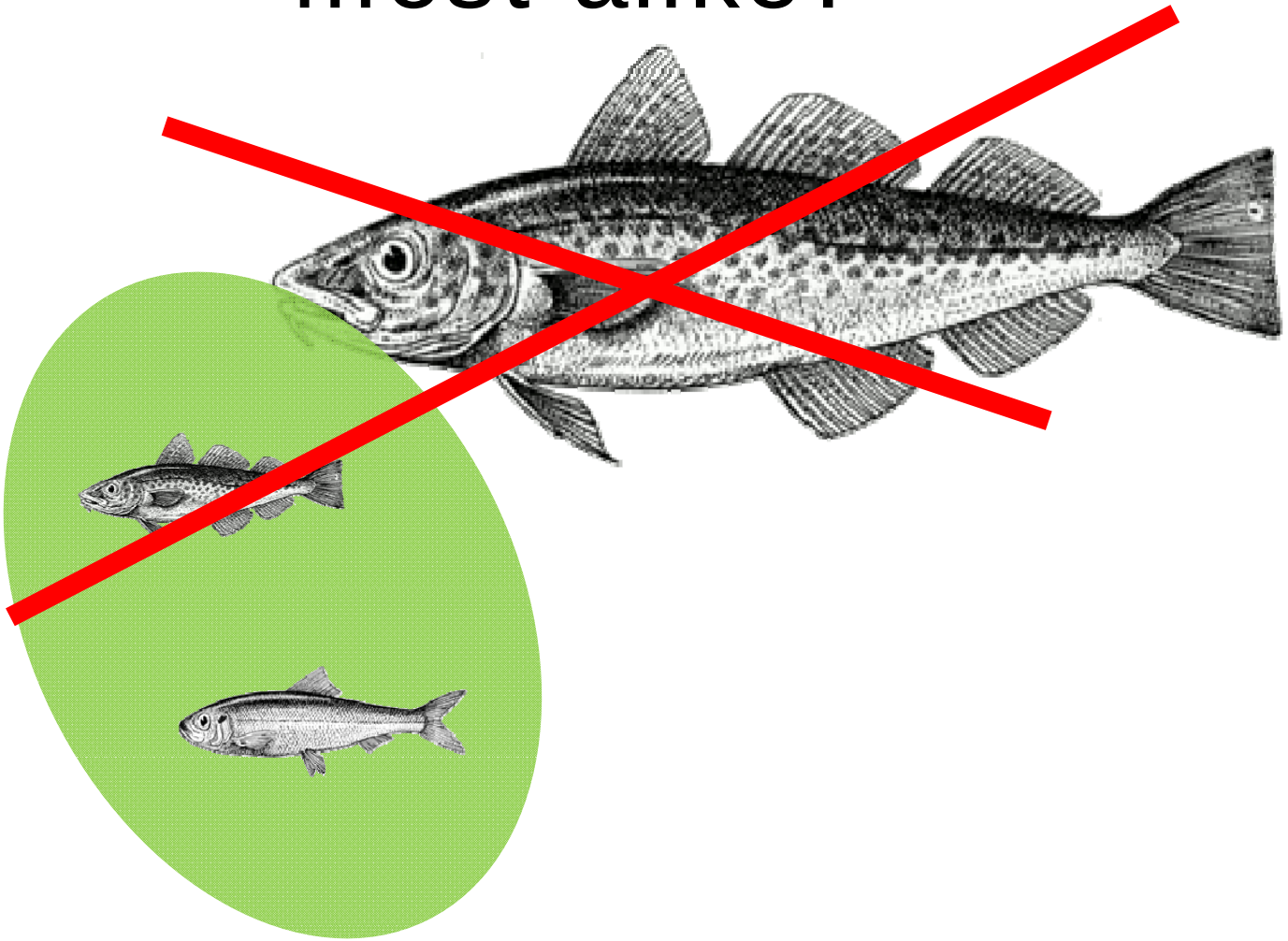


Yodzis (2000) Ecology

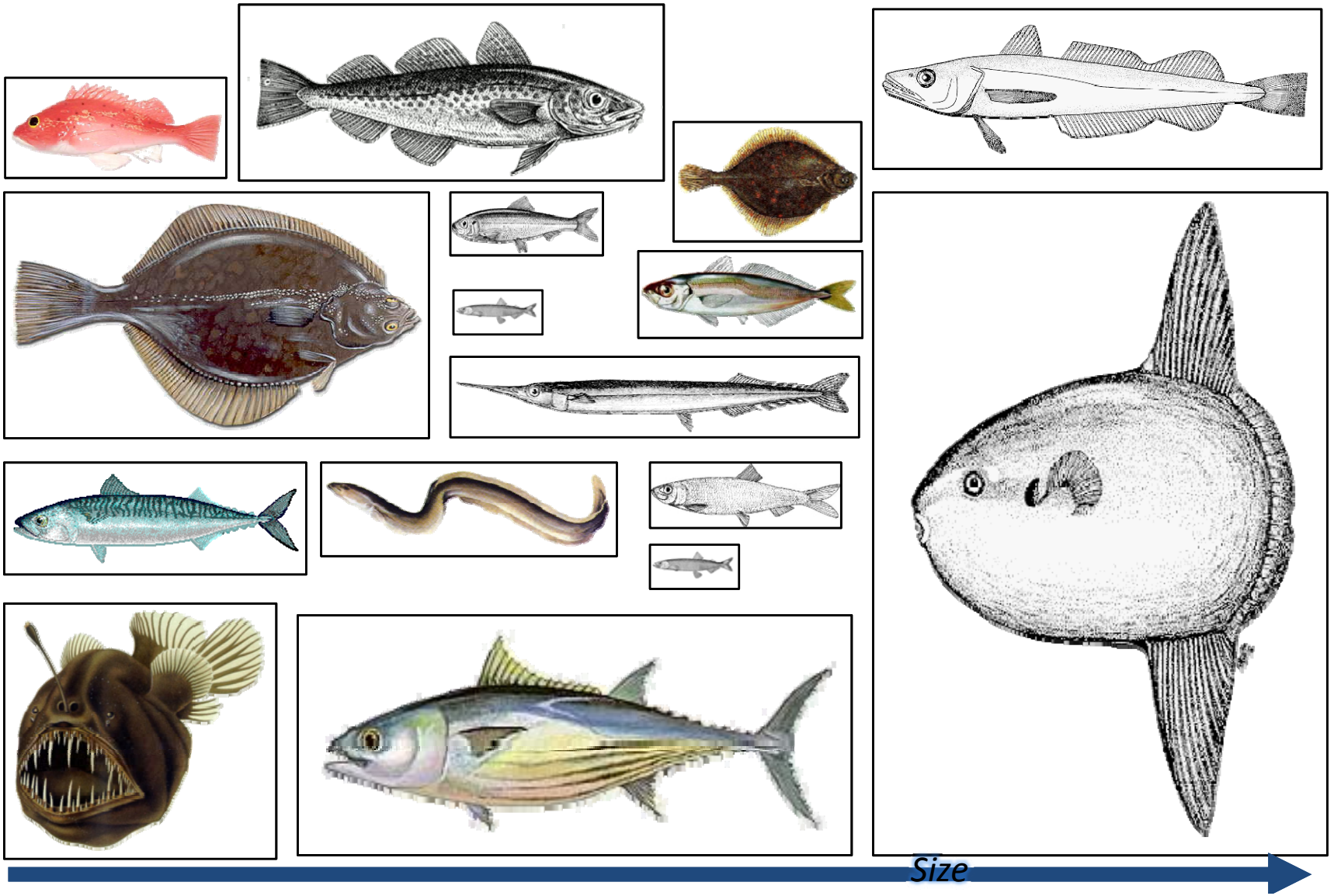
Which two fish are most alike?



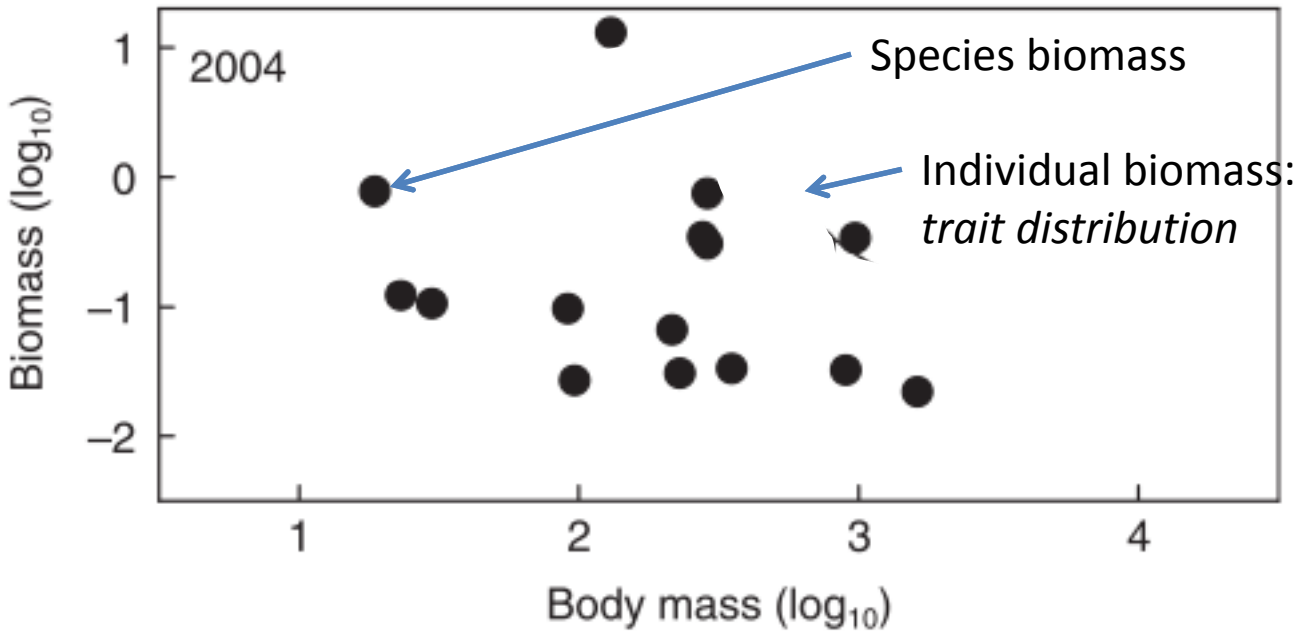
Which two fish are ecologically most alike?



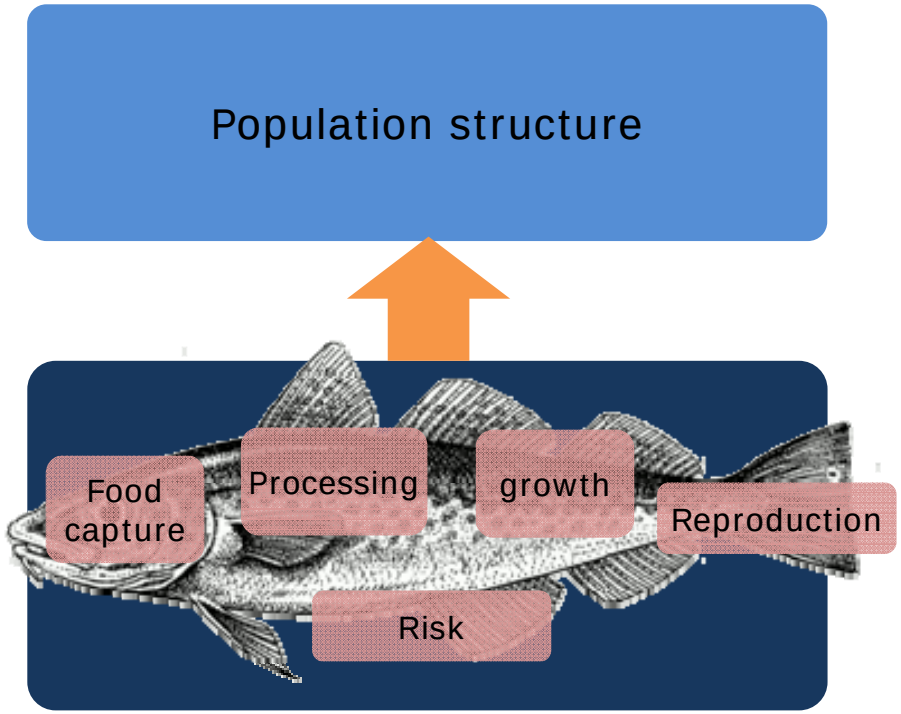
How do we characterize fish?



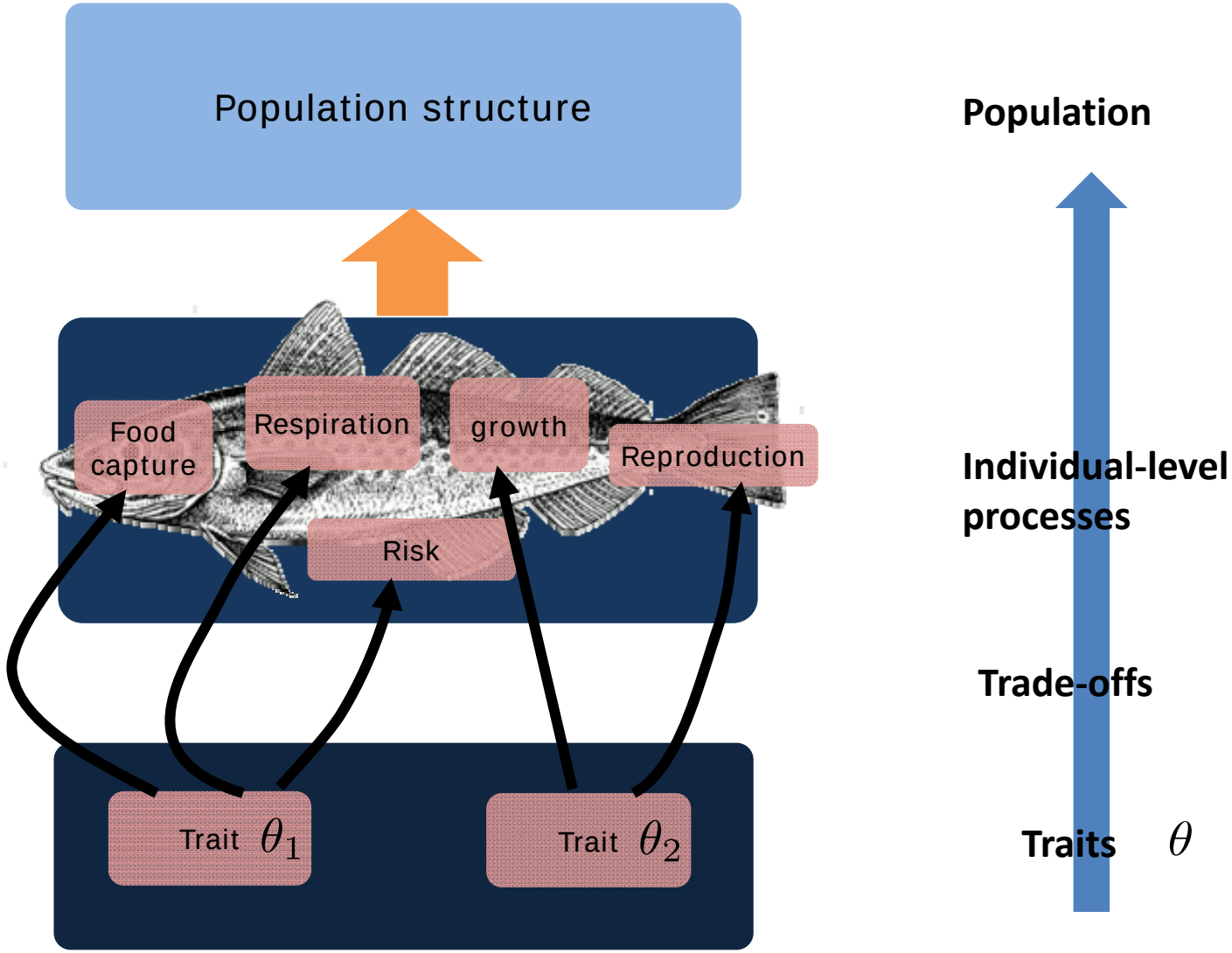
Species distributions vs. trait distribution

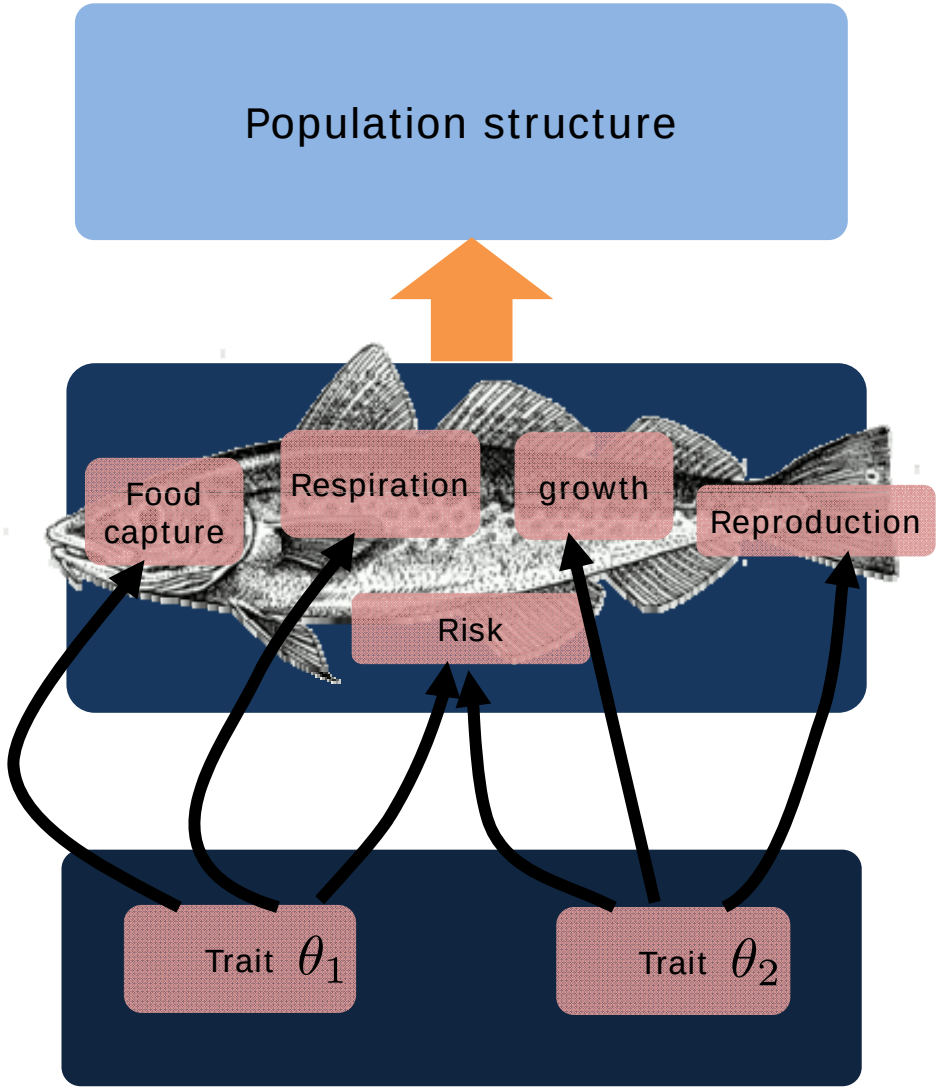


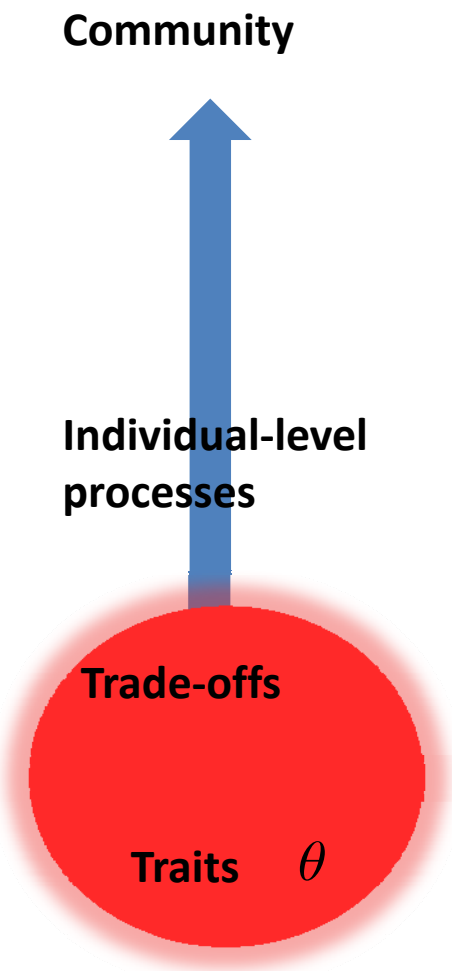
Jennings et al (2007) J. Anim. Ecol.



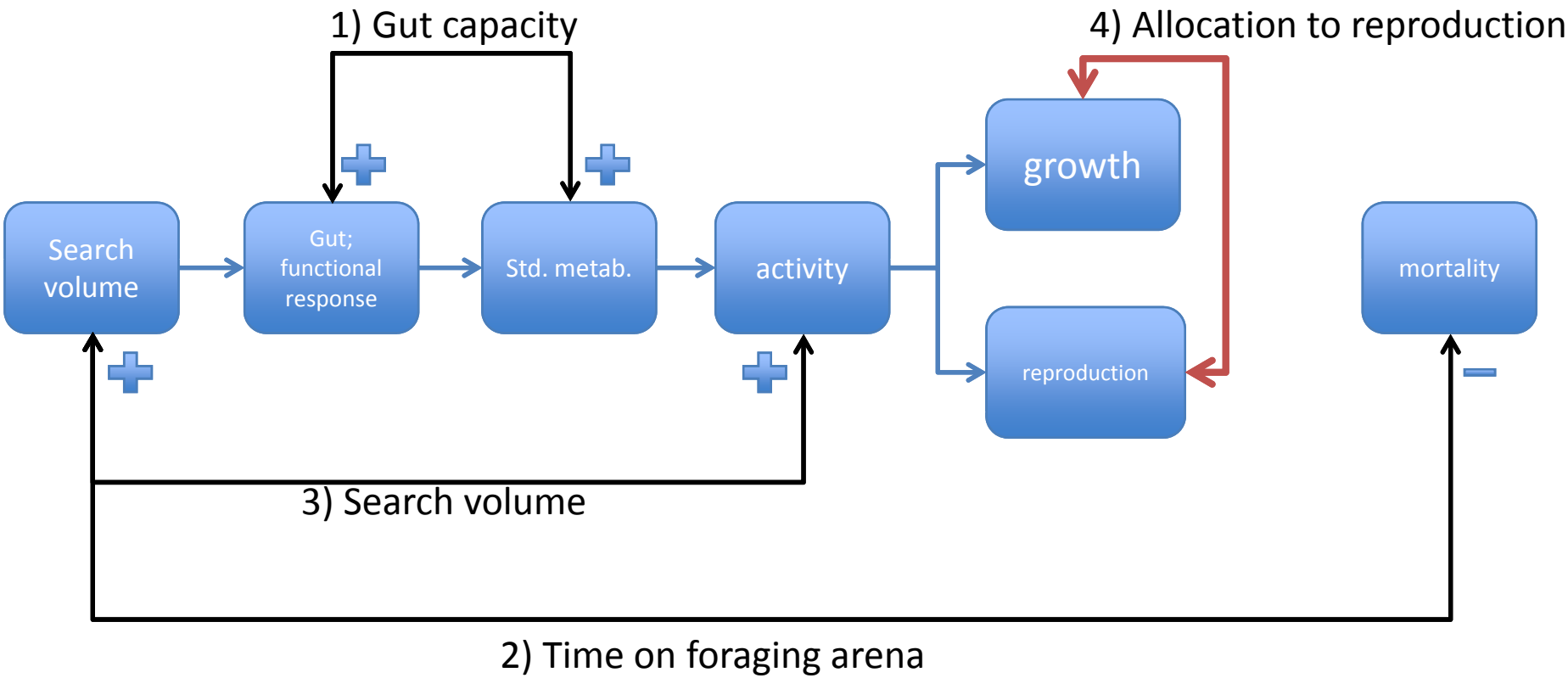
Individual level processes


Population structure
Food capture
Respiration
growth
Reproduction
Risk
Trait θ_1
Trait θ_2
Population
Individual-level processes
Trade-offs
Traits θ

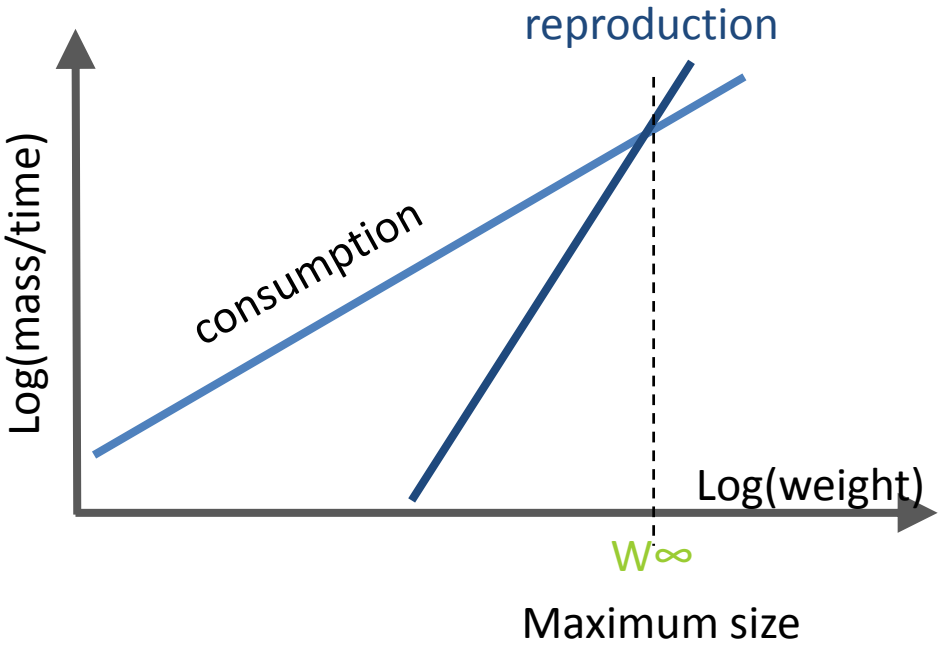

Population structure
Food capture
Respiration
growth
Reproduction
Risk
Trait θ_1
Trait θ_2

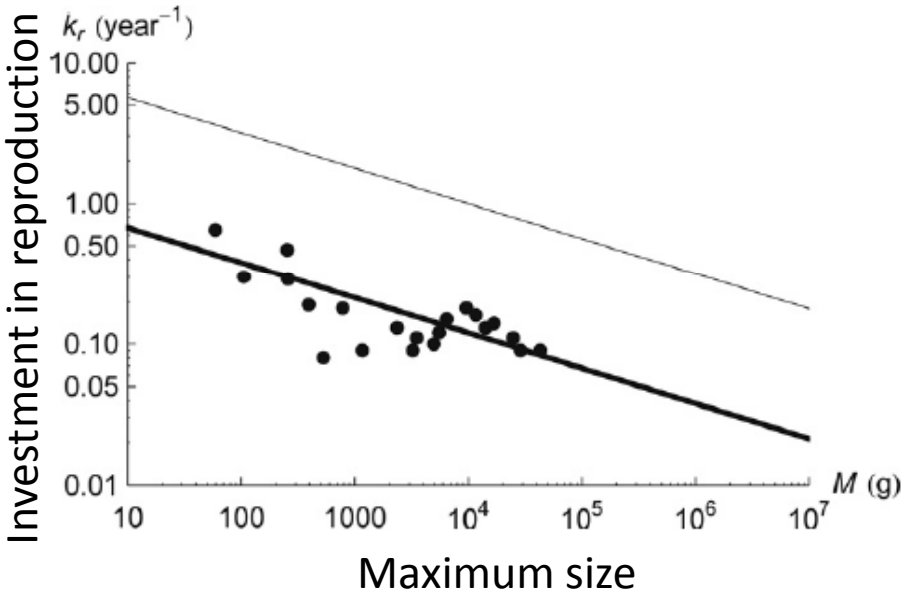

Community
Individual-level processes
Trade-offs
Traits θ

The mechanistic approach to trade-offs

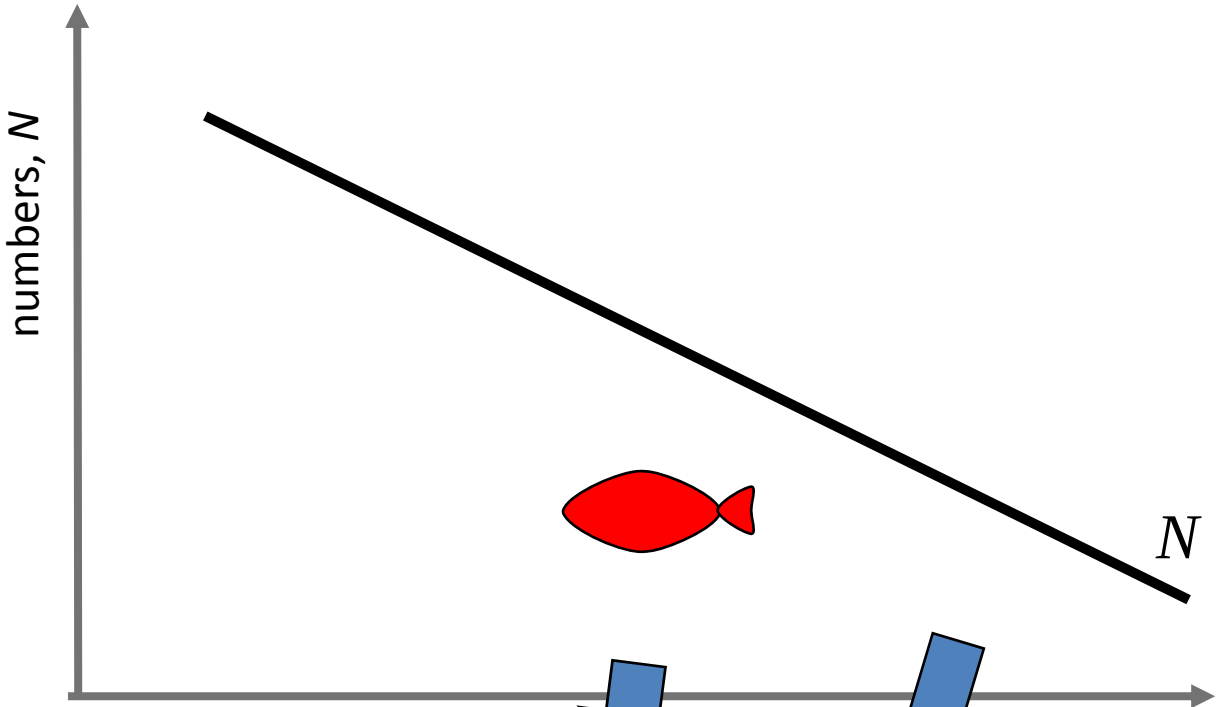


Tradeoff between growth and reproduction





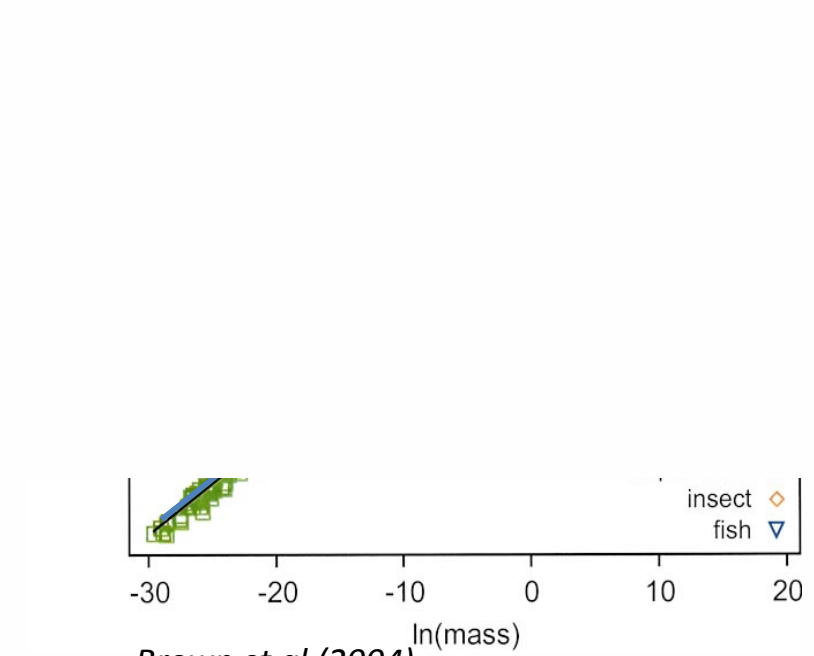
Model of the size distribution



$$\frac{\partial N}{\partial t} + \frac{\partial gN}{\partial w} = -\mu N$$

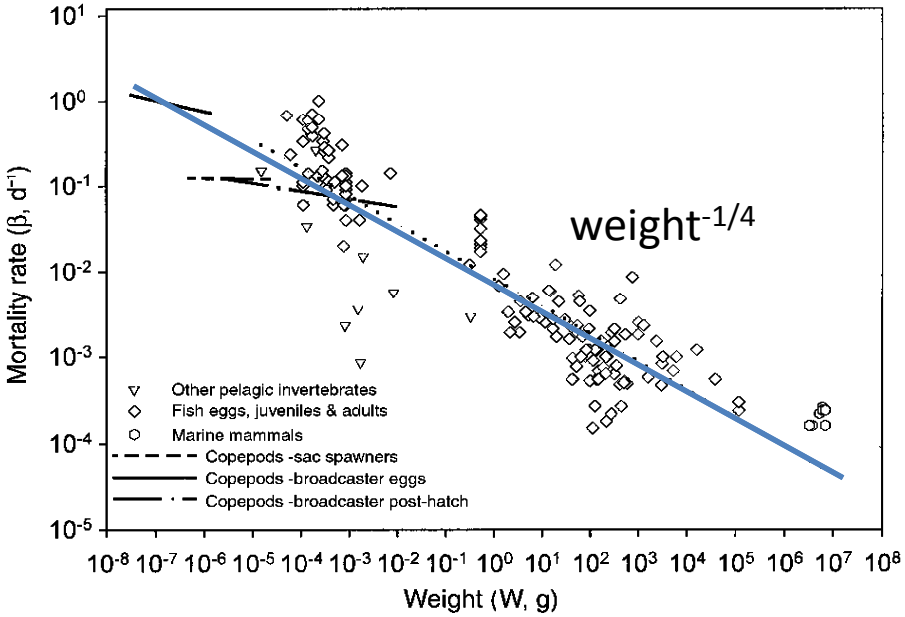
Metabolic assumptions

Metabolism



Brown et al (2004)

Mortality

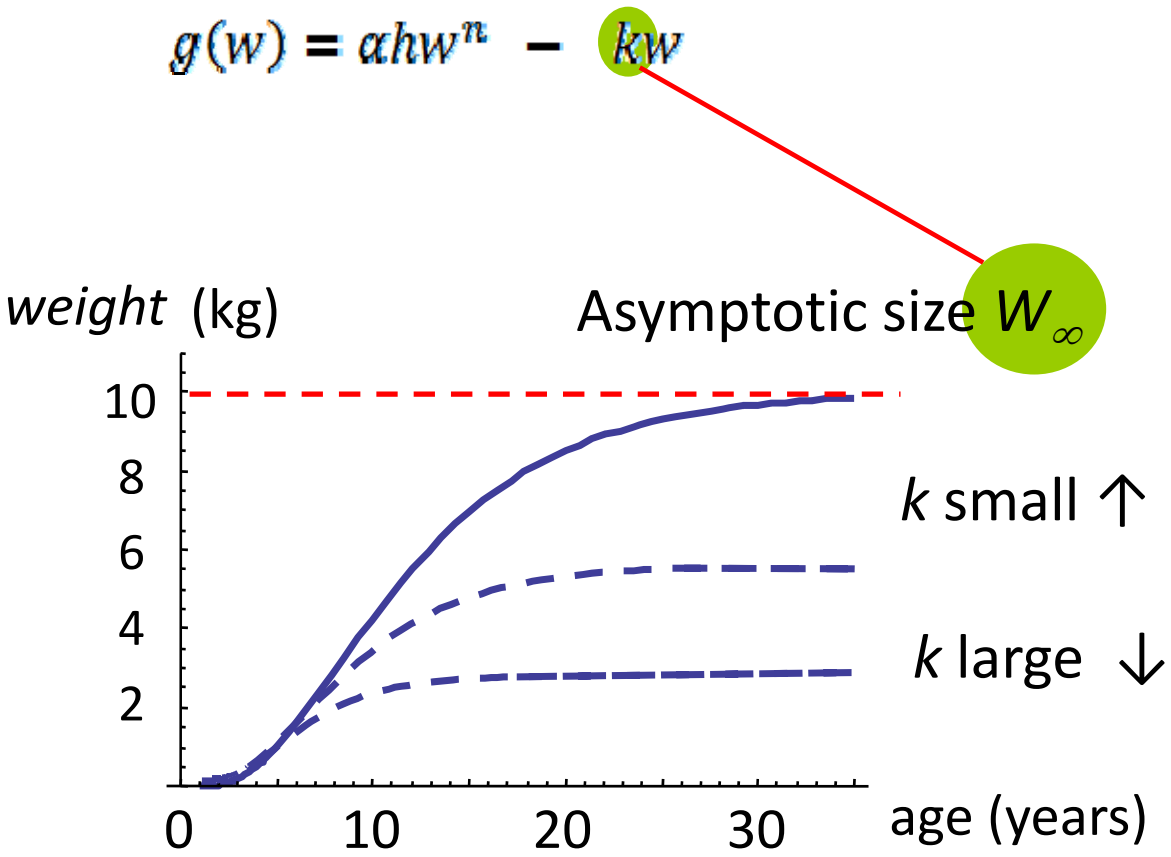


Hirst & Kiørboe (2002)

Traits and trade-offs

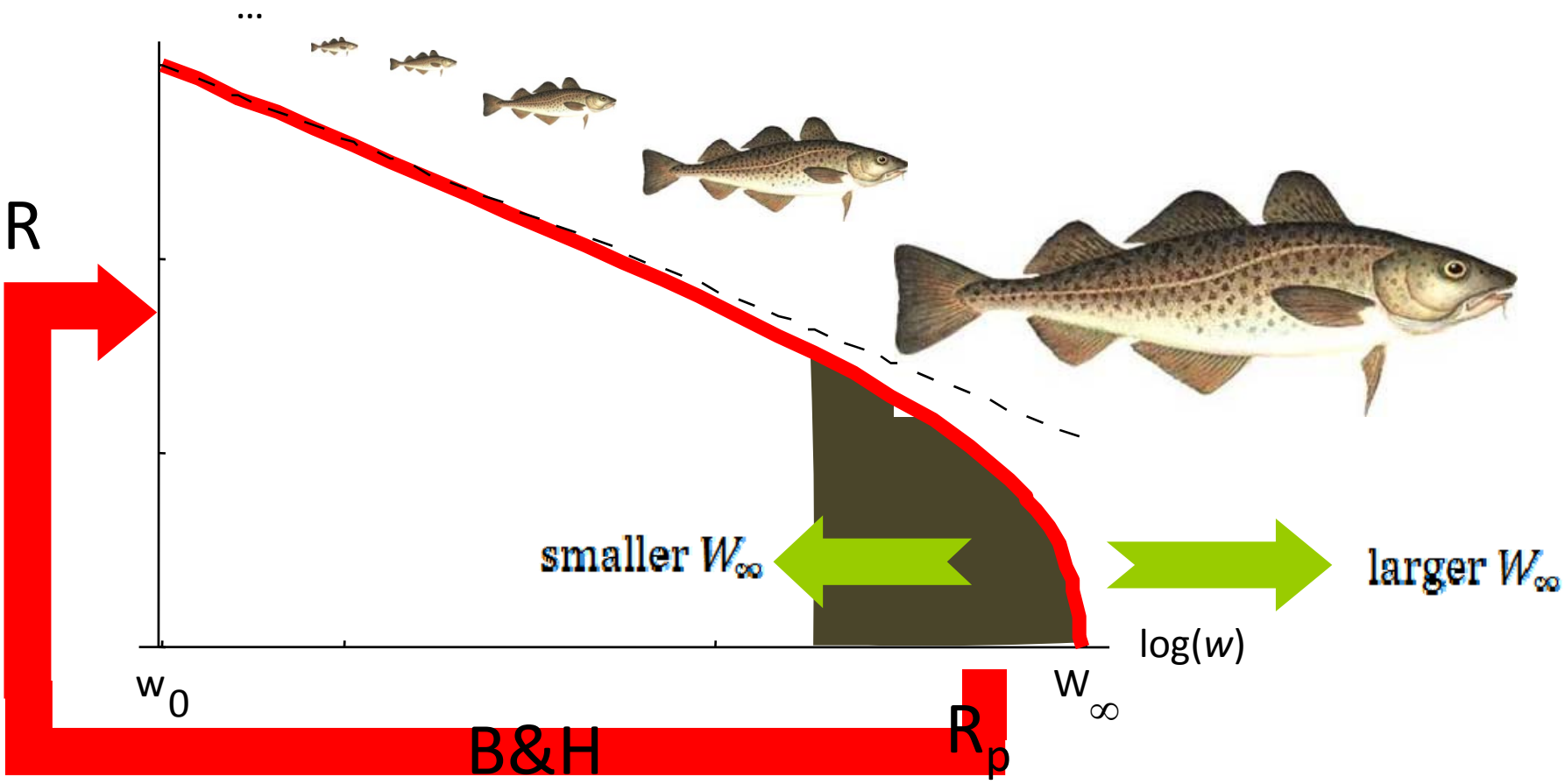
$$growth = \alpha \cdot consumption - reproduction$$

$$g(w) = \alpha h w^n - kw$$



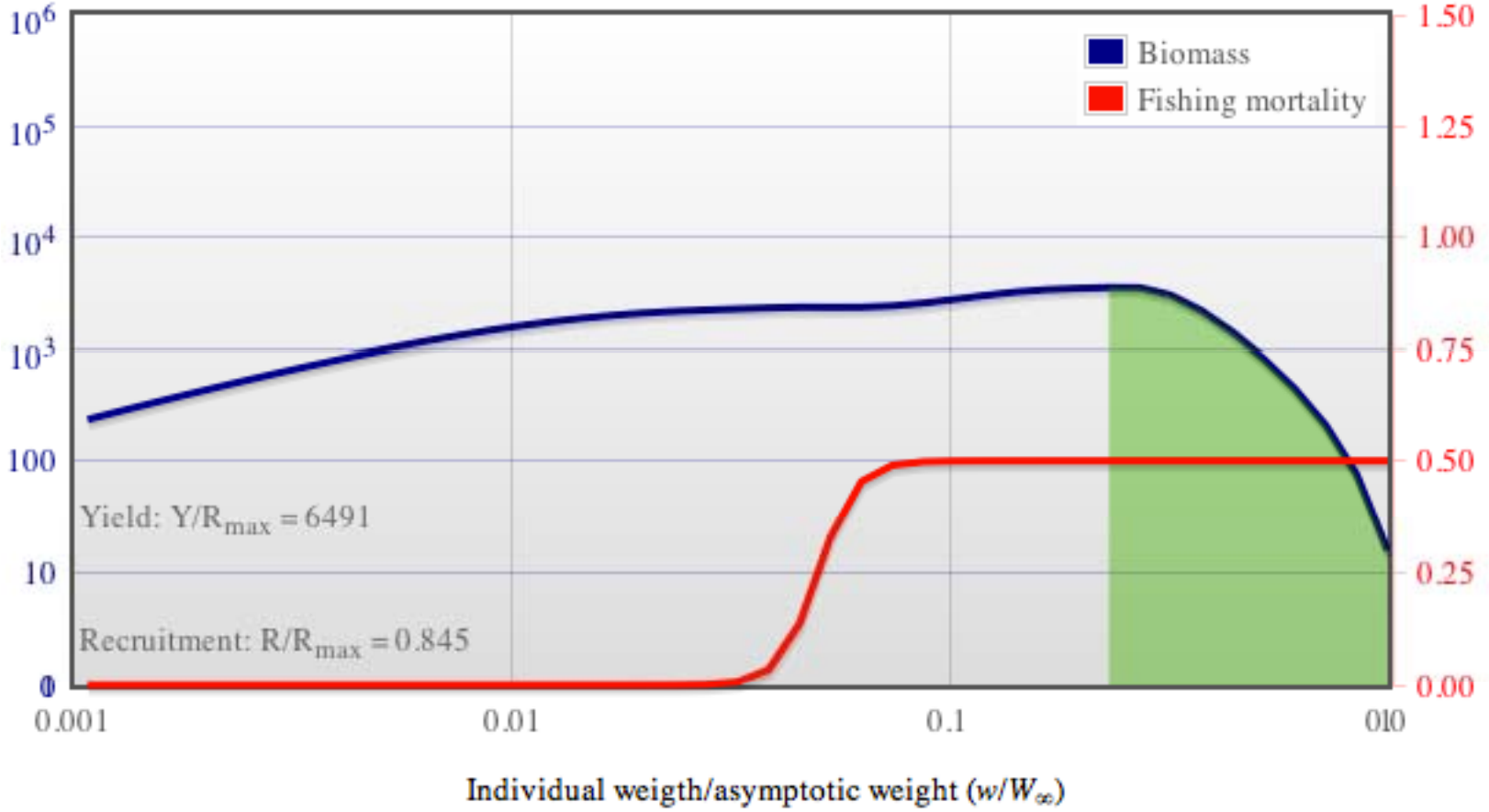
Andersen and Beyer 2006

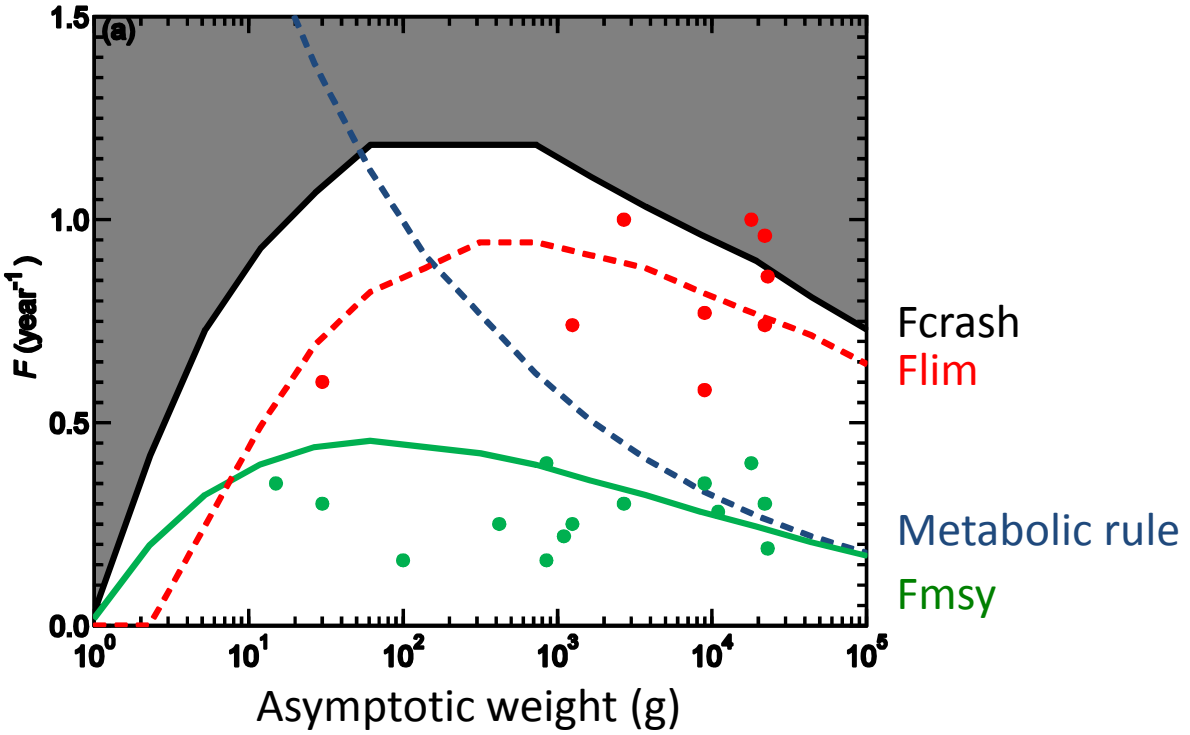
Single species perspective



Single-species simulator

http://stockassessment.org/singlespeciessizespectrum/





Reference points do not obey metabolic scaling rules

Andersen and Beyer (2013)

Try the “evolutionary calculator” on http://bestandsvurdering.dk/Evolution.

Evolutionary Calculator

Calculate the expected rate of fisheries induced evolution on a stock. The chosen values are for Baltic cod.

Biological parameters

Asymptotic (maximum) weight	22000	grams
Von Bertalanffy growth rate (K)	0.15	$year^{-1}$ (default is 4.5 (asymptotic weight)$^{-0.33}$)
Adult natural mortality	0.2	$year^{-1}$ (default is 1.3 K)
Size at maturation	1500	grams (default is asymptotic weight/4)

Fishing

Fishing mortality	0.7	$year^{-1}$
Minimum fished size	1000	gram
Fishing mortality on spawners	0.3	$year^{-1}$

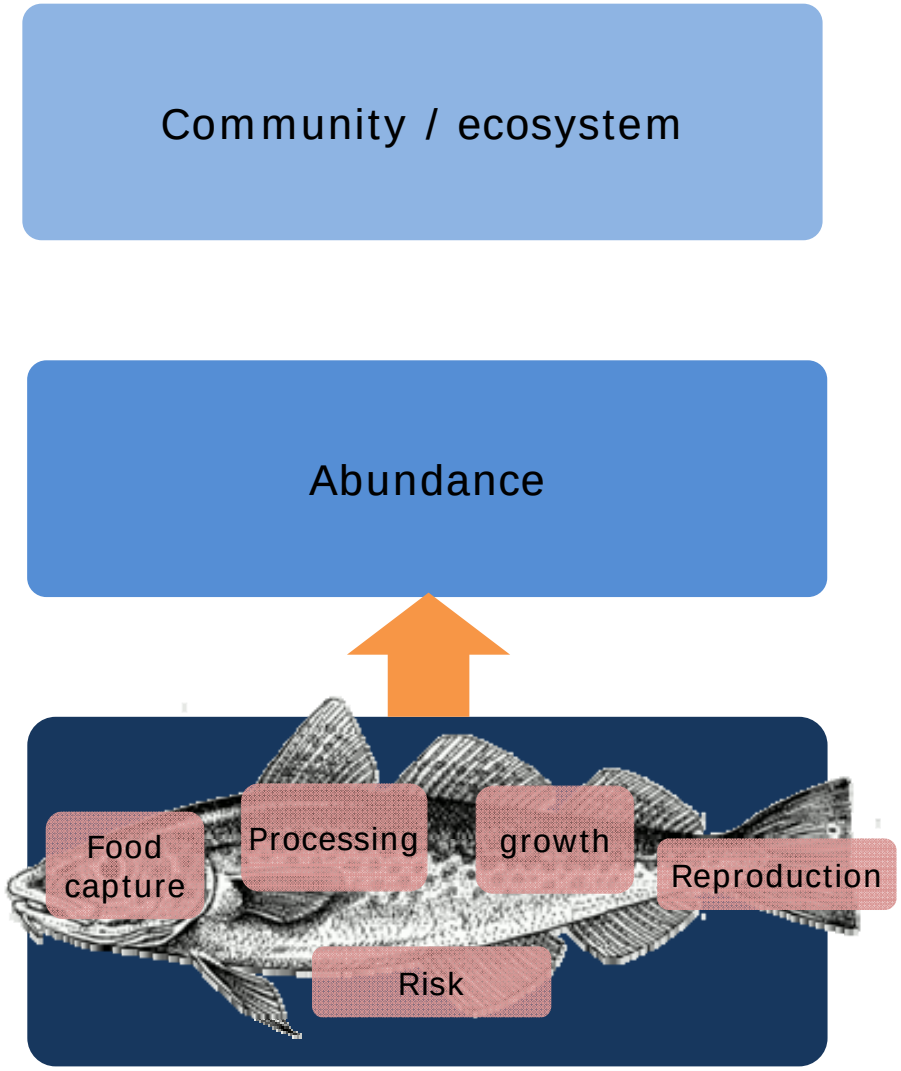
Calculate

Results

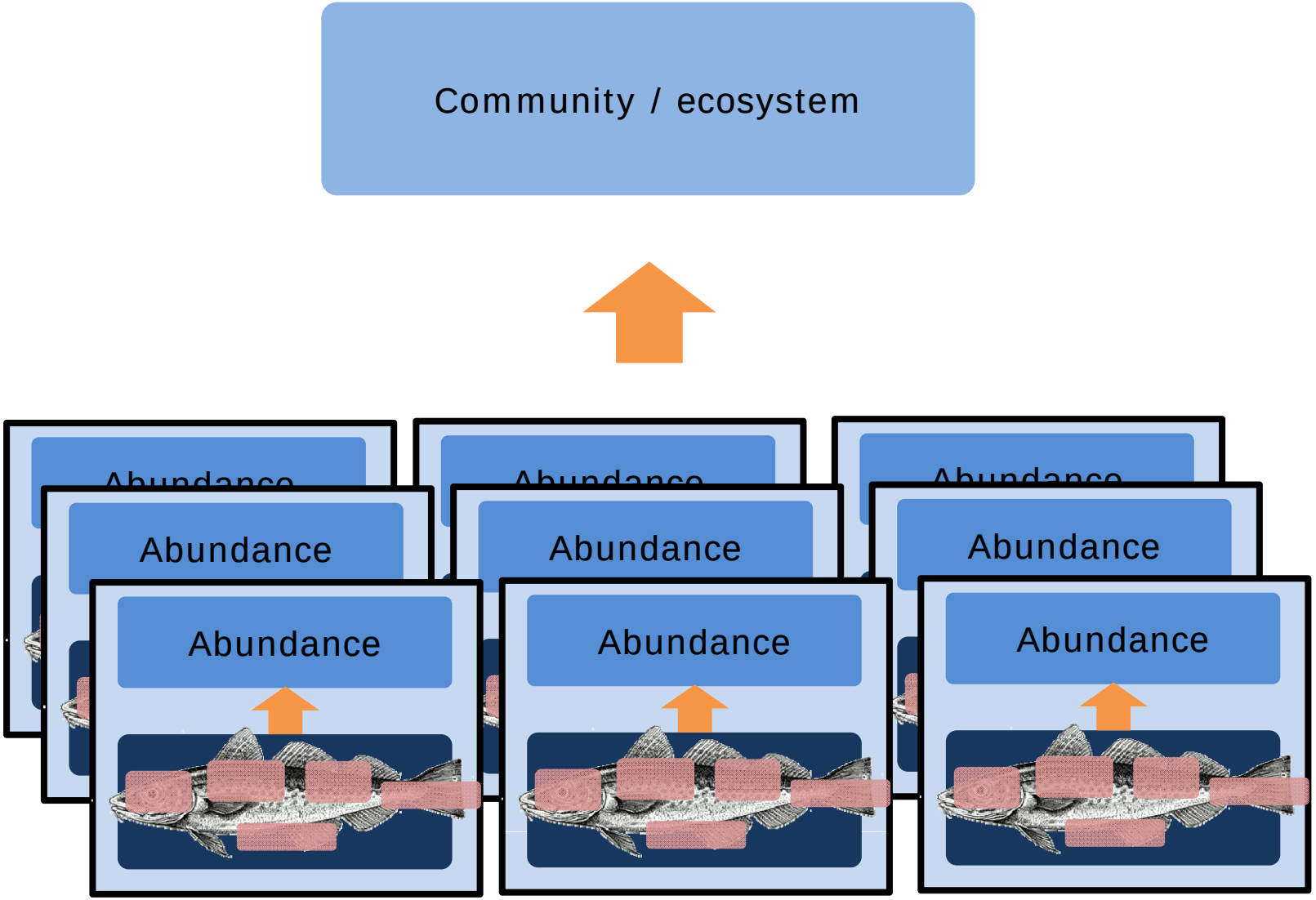
Press [Calculate] to perform calculation.

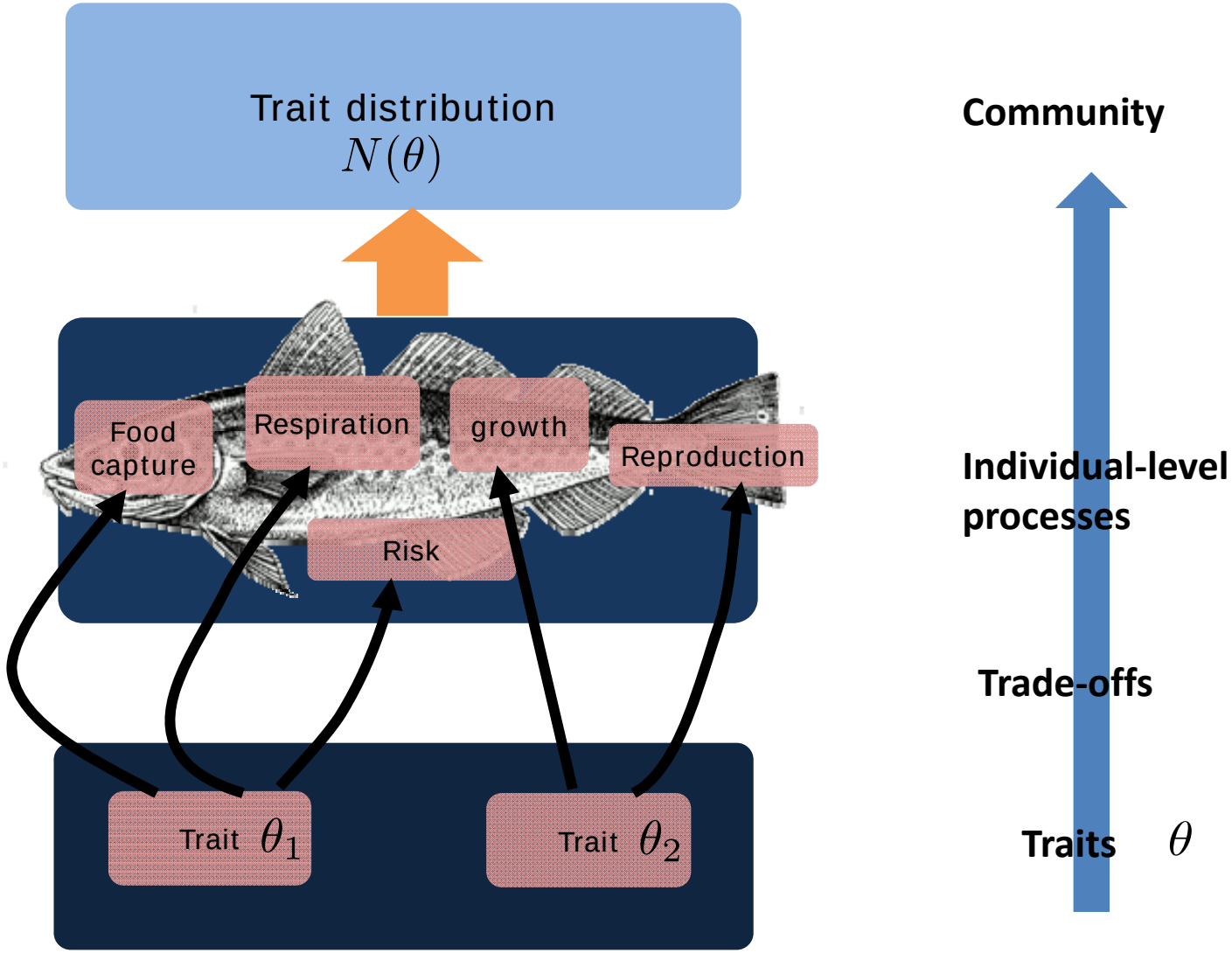
The calculations are based on the model in Andersen and Brander *PNAS* 106(28) 11657-11660 (2009). Note that the model is based on a number of assumptions, see the article for details. Output of the model should not be used in a practical management setting without first consulting the authors. The R code for the model is here. Php code by Casper Berg. R-code by Ken Andersen. September 2009.

How?



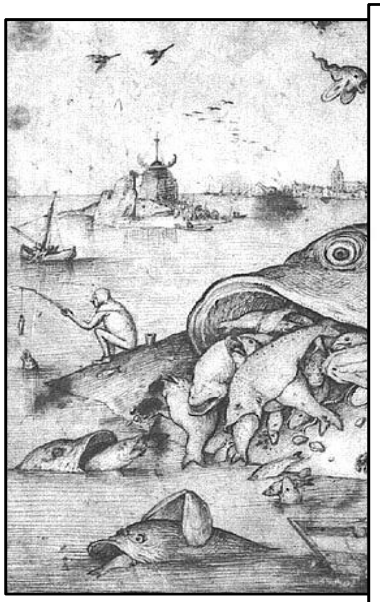
Individual level processes


Community / ecosystem
Abundance
Abundance
Abundance
Abundance
Abundance
Abundance

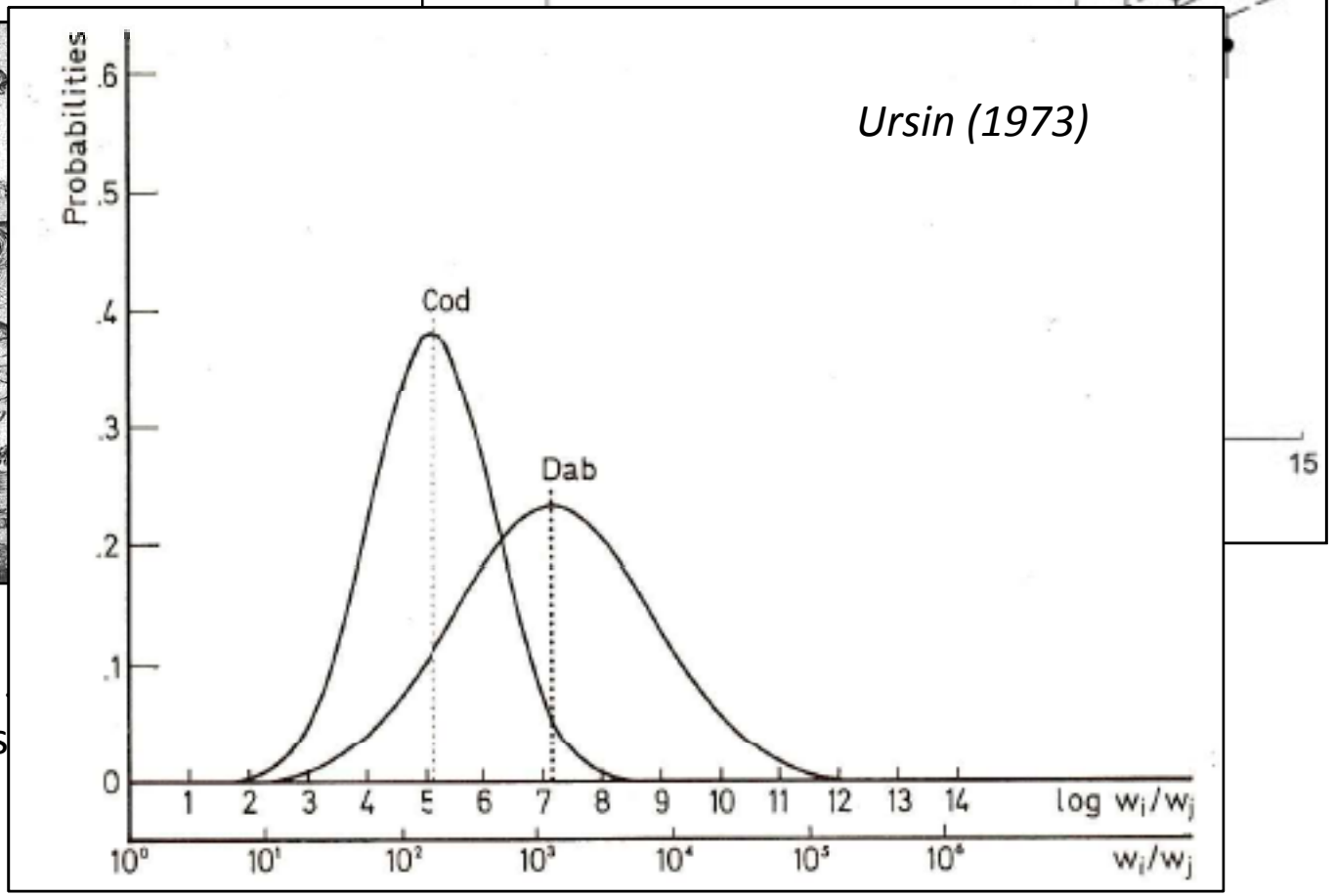

Trait distribution
$N(\theta)$
Food capture
Respiration
growth
Reproduction
Risk
Trait θ_1
Trait θ_2
Community
Individual-level processes
Trade-offs
Traits θ

Who eats whom

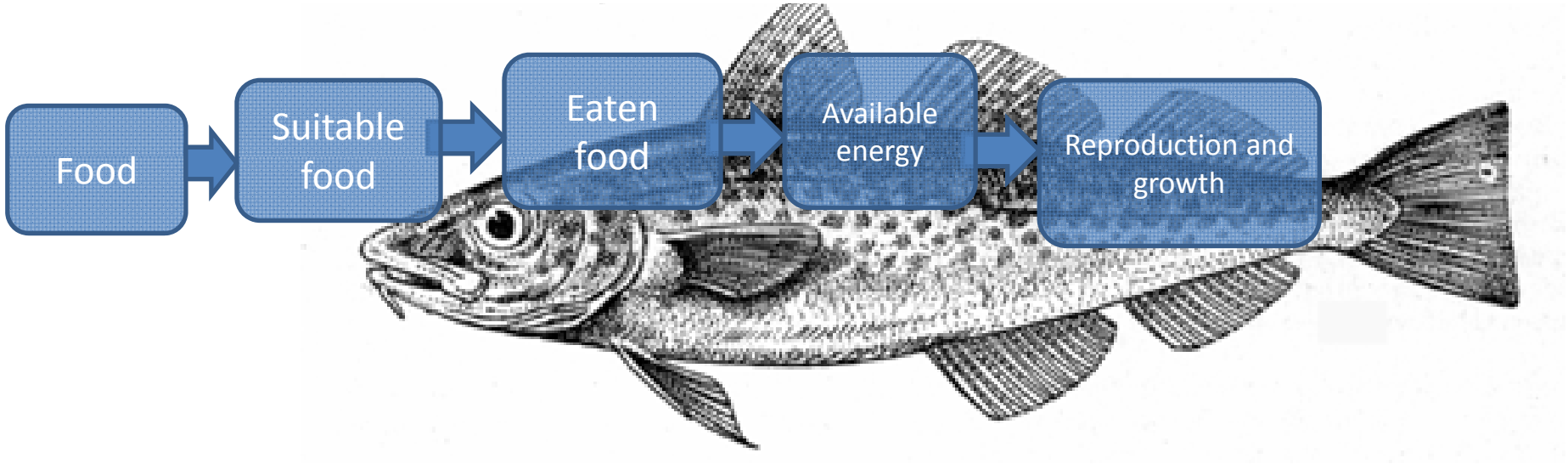
Third Fisherman: Master, I marvel how the fishes live in the sea.
First Fisherman: Why, as men do a-land; the great ones eat up the little ones.
Shakespeare, Pericles 2.1.69-70

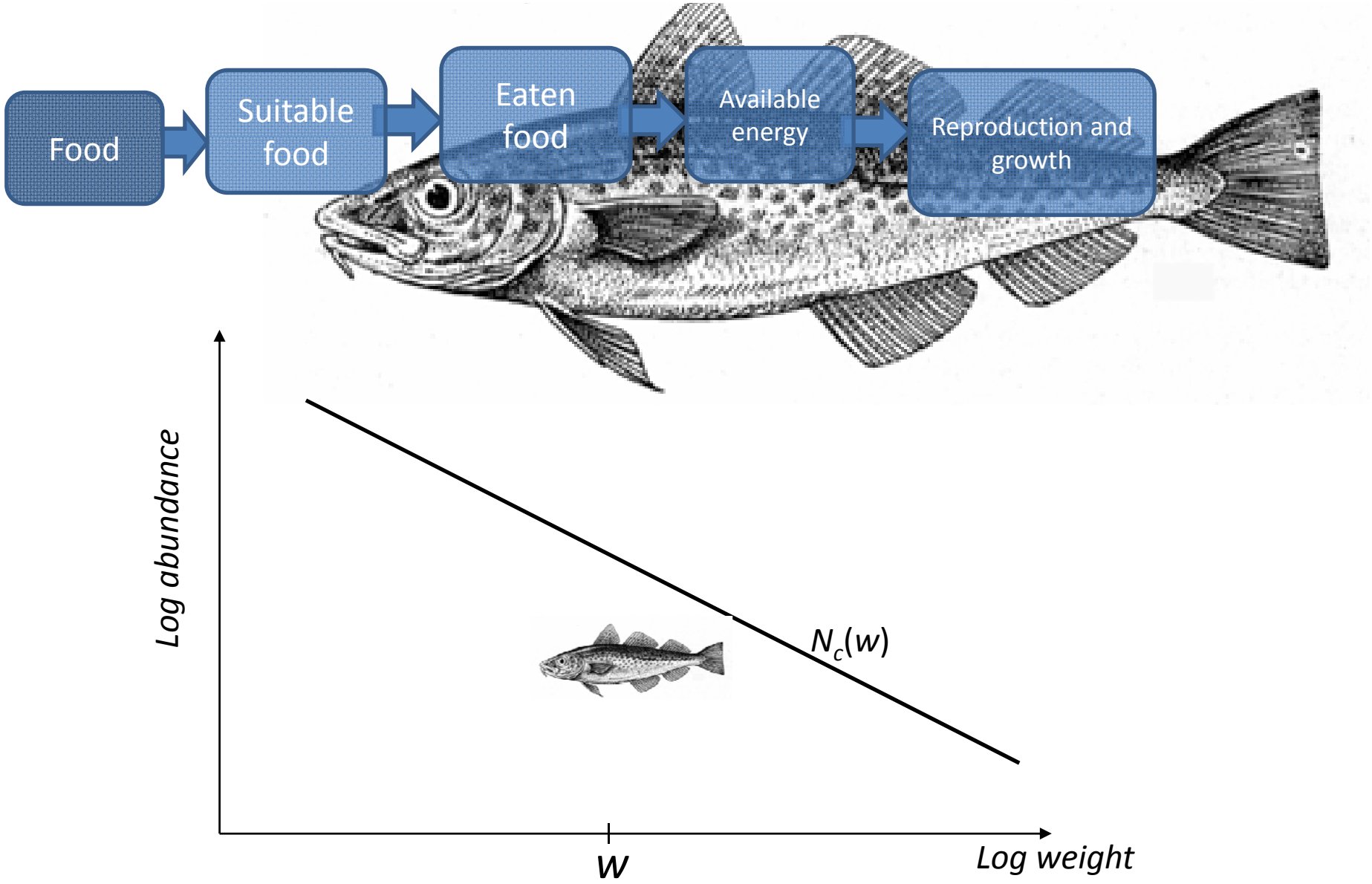


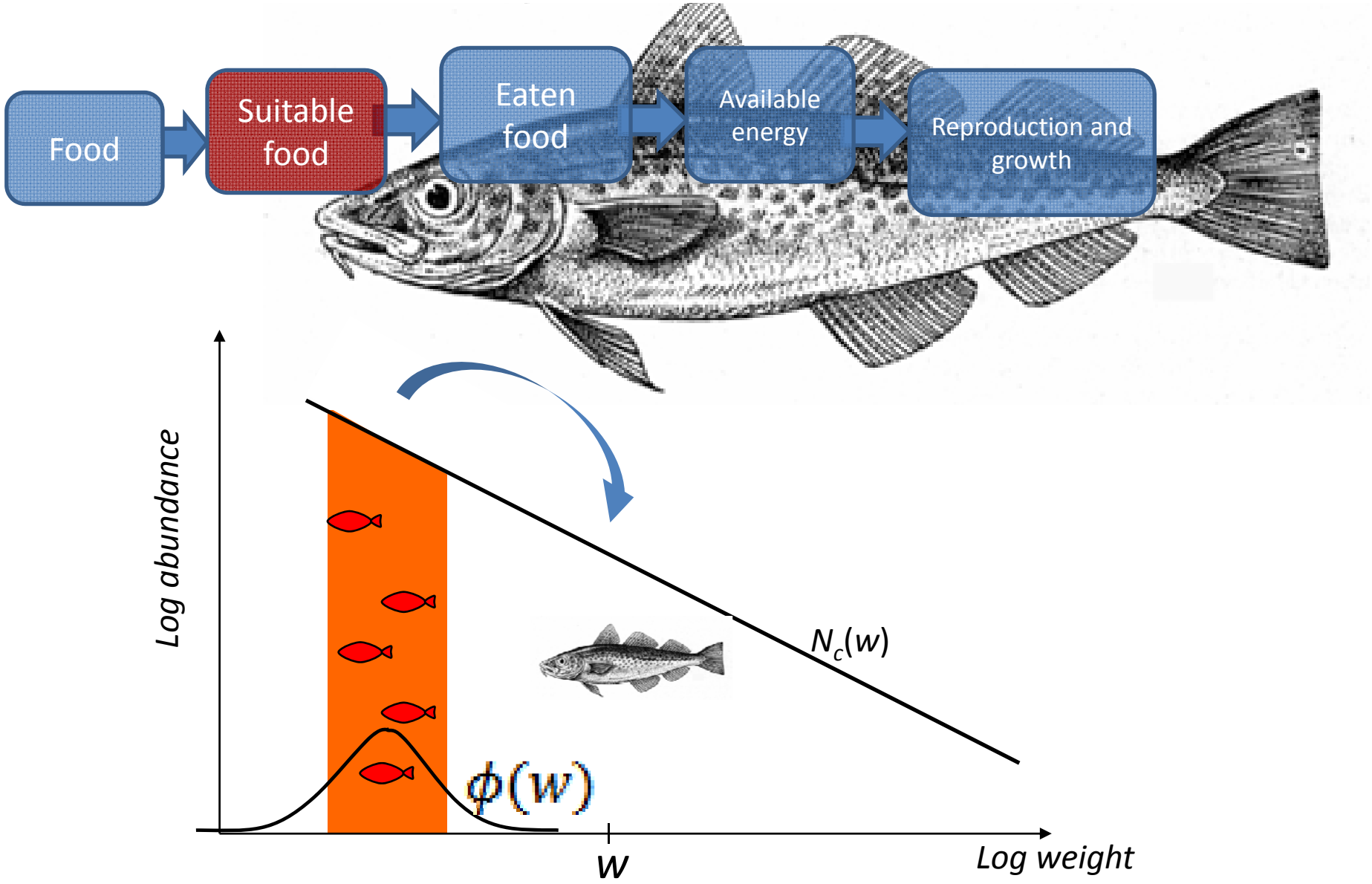
"Grandibus exigui
Due to differences



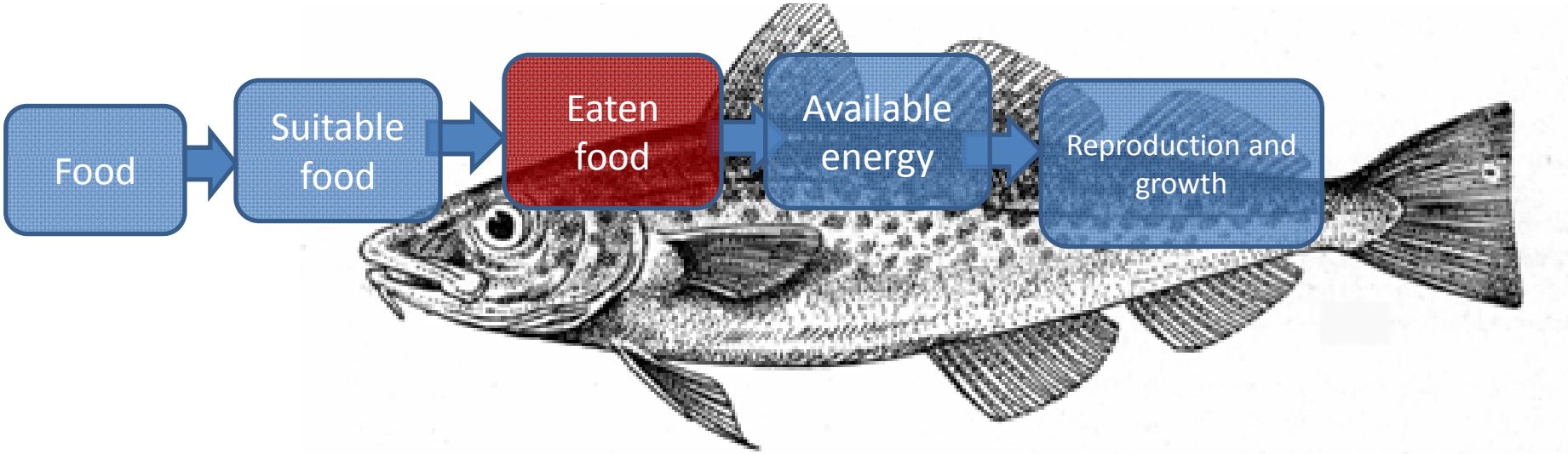
Ursin (1973)

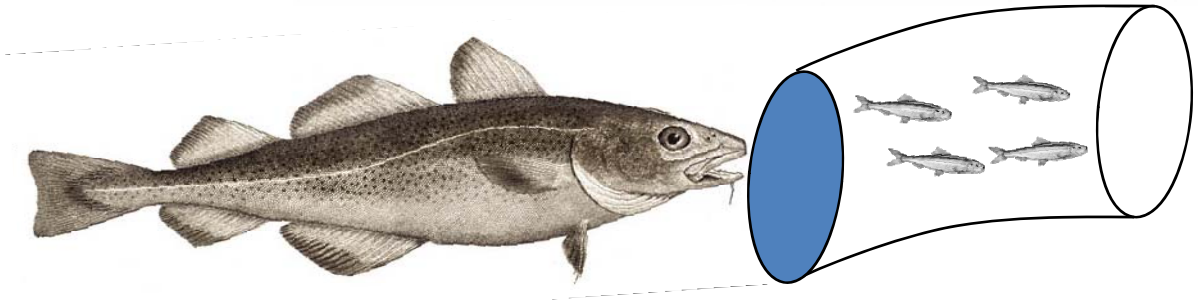

Food
Suitable food
Eaten food
Available energy
Reproduction and growth


Food
Suitable food
Eaten food
Available energy
Reproduction and growth
Log abundance
$N_c(w)$
w
Log weight



$$\int_0^\infty N_c(w_{prey}) w_{prey} \phi(w_{prey}) dw_{prey}$$

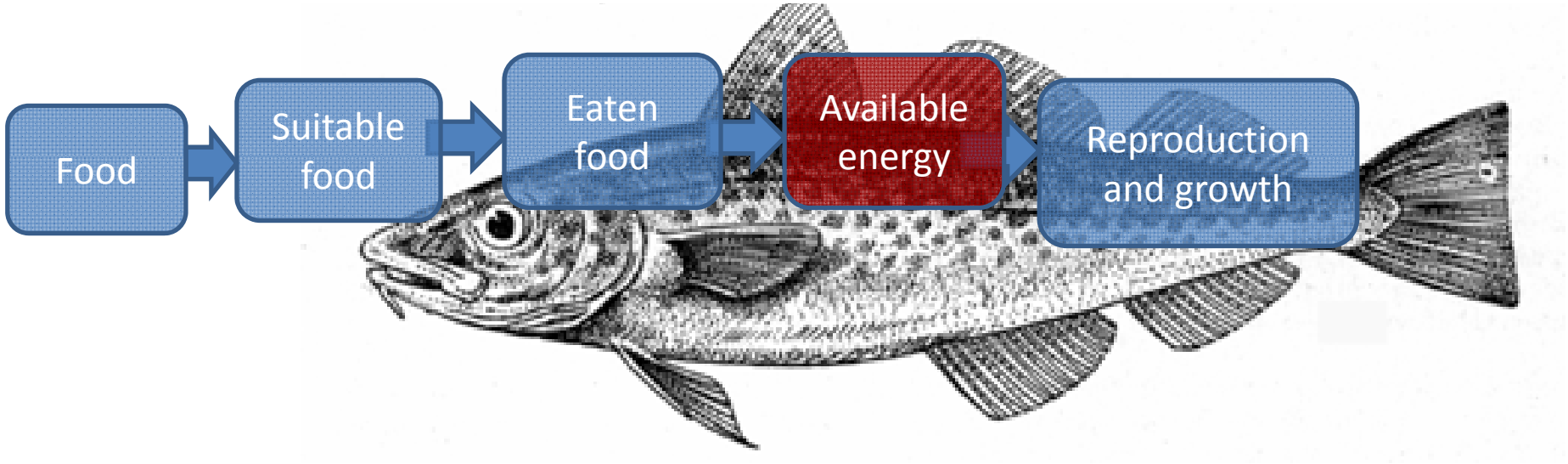




Caught food = search volume · suitable food

$$\gamma w^q \int_0^\infty N_c(w_{prey}) w_{prey} \phi(w_{prey}) dw_{prey}$$

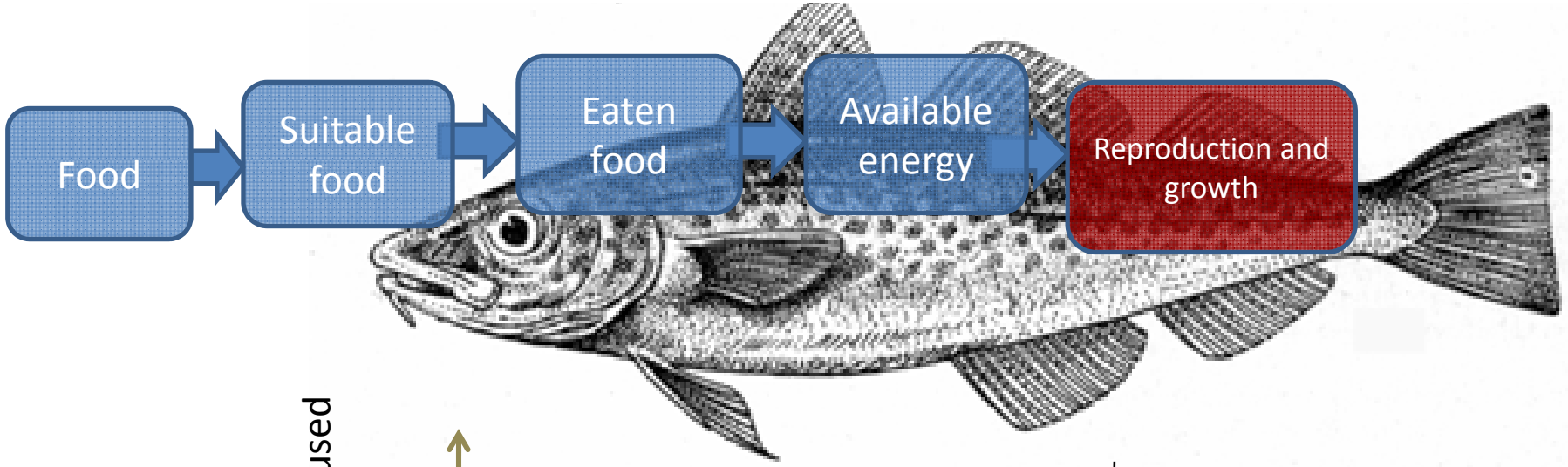
(+ satiation)

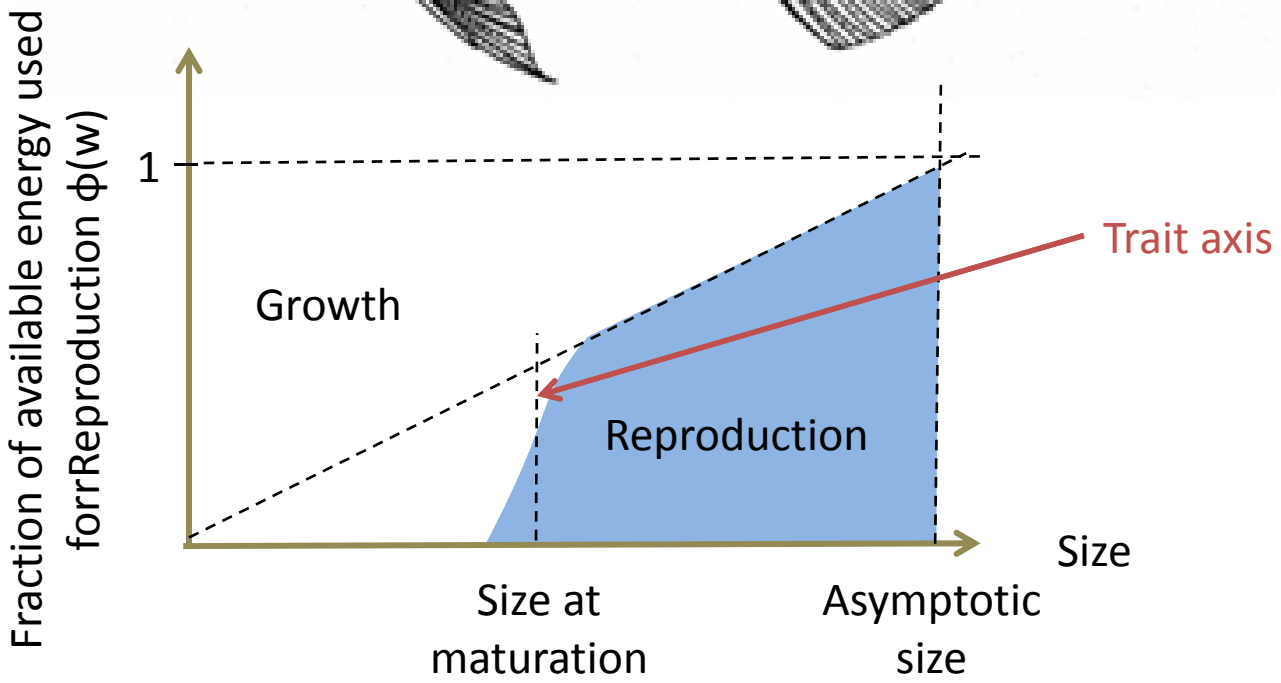


Assimilation efficiency

Standard metabolism

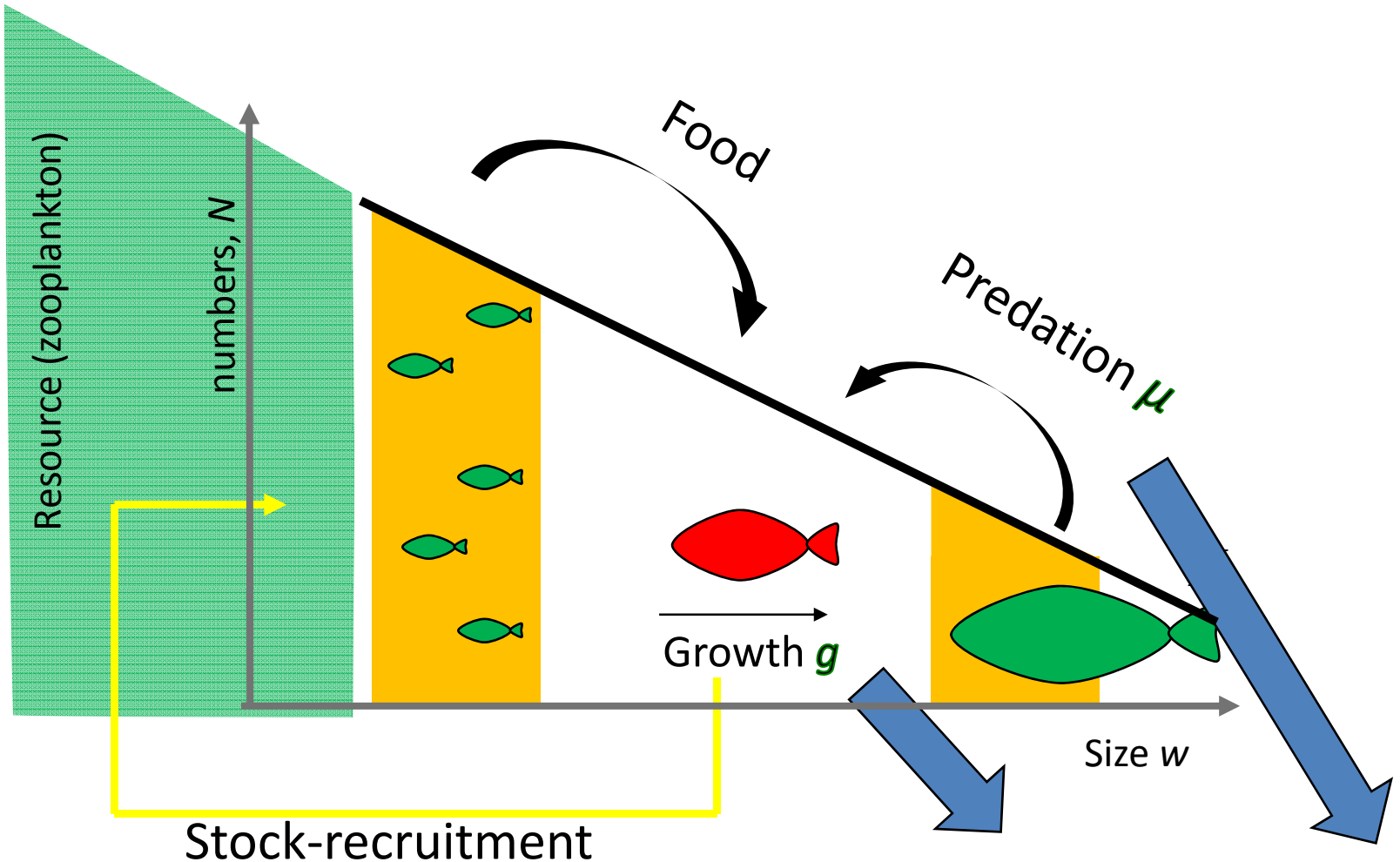
$$\alpha\gamma w^q \int_0^\infty N_c(w_{prey}) w_{prey} \phi(w_{prey}) dw_{prey} - kw^n$$



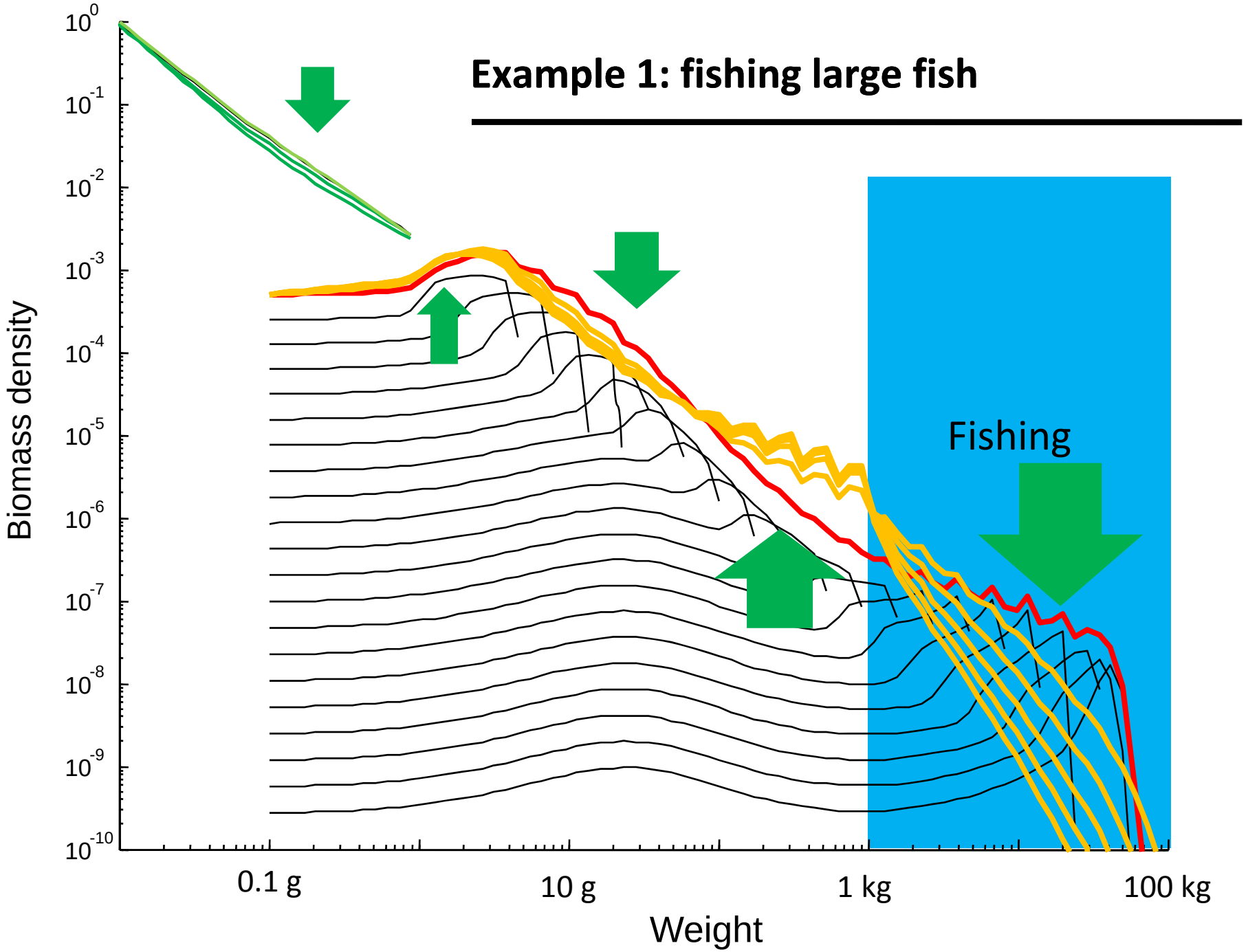


$$g(w) = (1 - \psi(w/W_\infty)) \left(\alpha\gamma w^q \int_0^\infty N_c(w_p) w_p \phi(w_p) dw_p - kw^n \right)$$

Model of the trait distribution



$$\frac{\partial N(w, W_\infty)}{\partial t} + \frac{\partial g N(w, W_\infty)}{\partial w} = \mu N(w, W_\infty)$$


Example 1: fishing large fish
Biomass density
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
Fishing
0.1 g
10 g
1 kg
100 kg
Weight

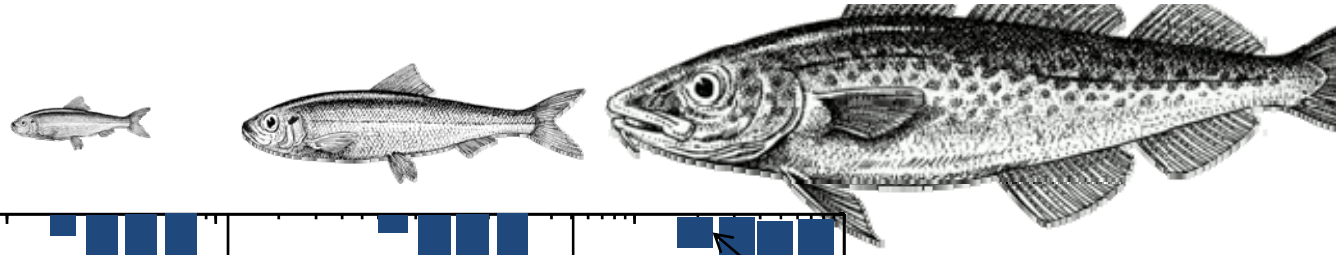
Example #2: Conflicting objectives

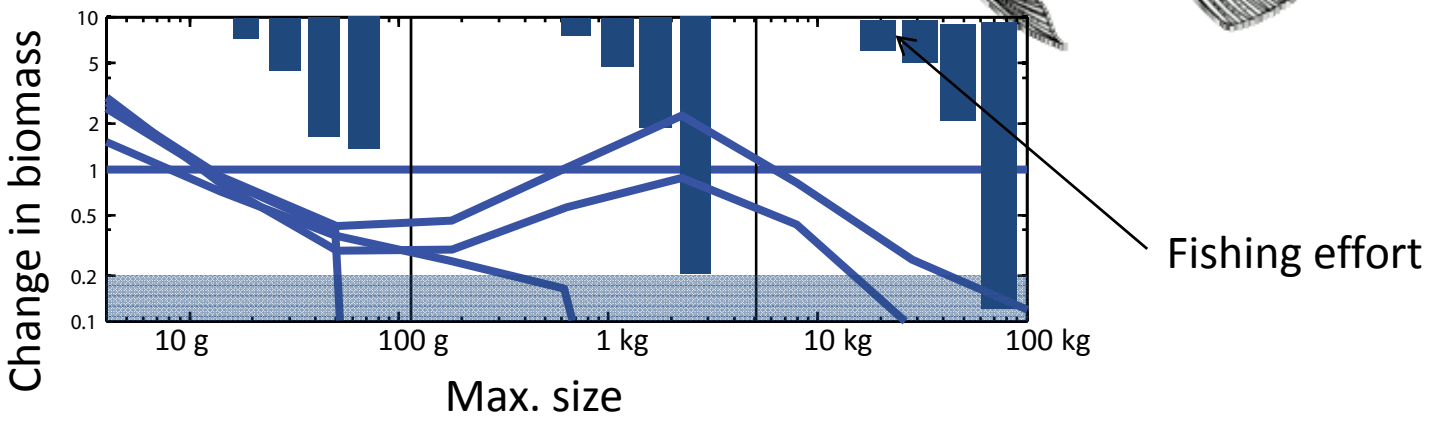
What do we want?

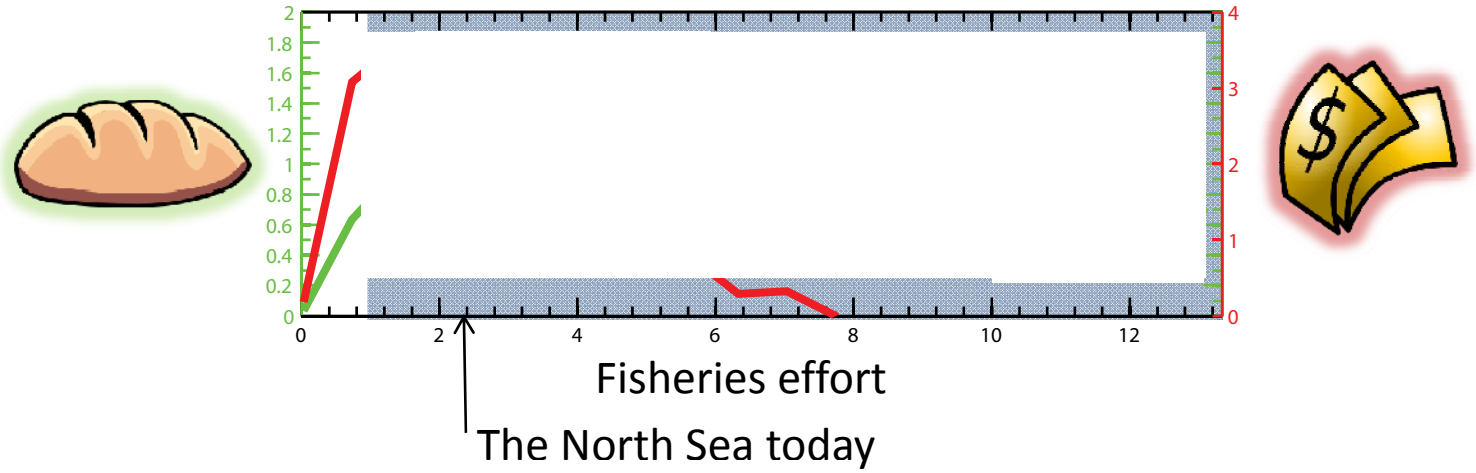
Feed the world -> maximize protein yield

Earn money -> maximize profit

Conserve ecosystem function -> avoid collapse







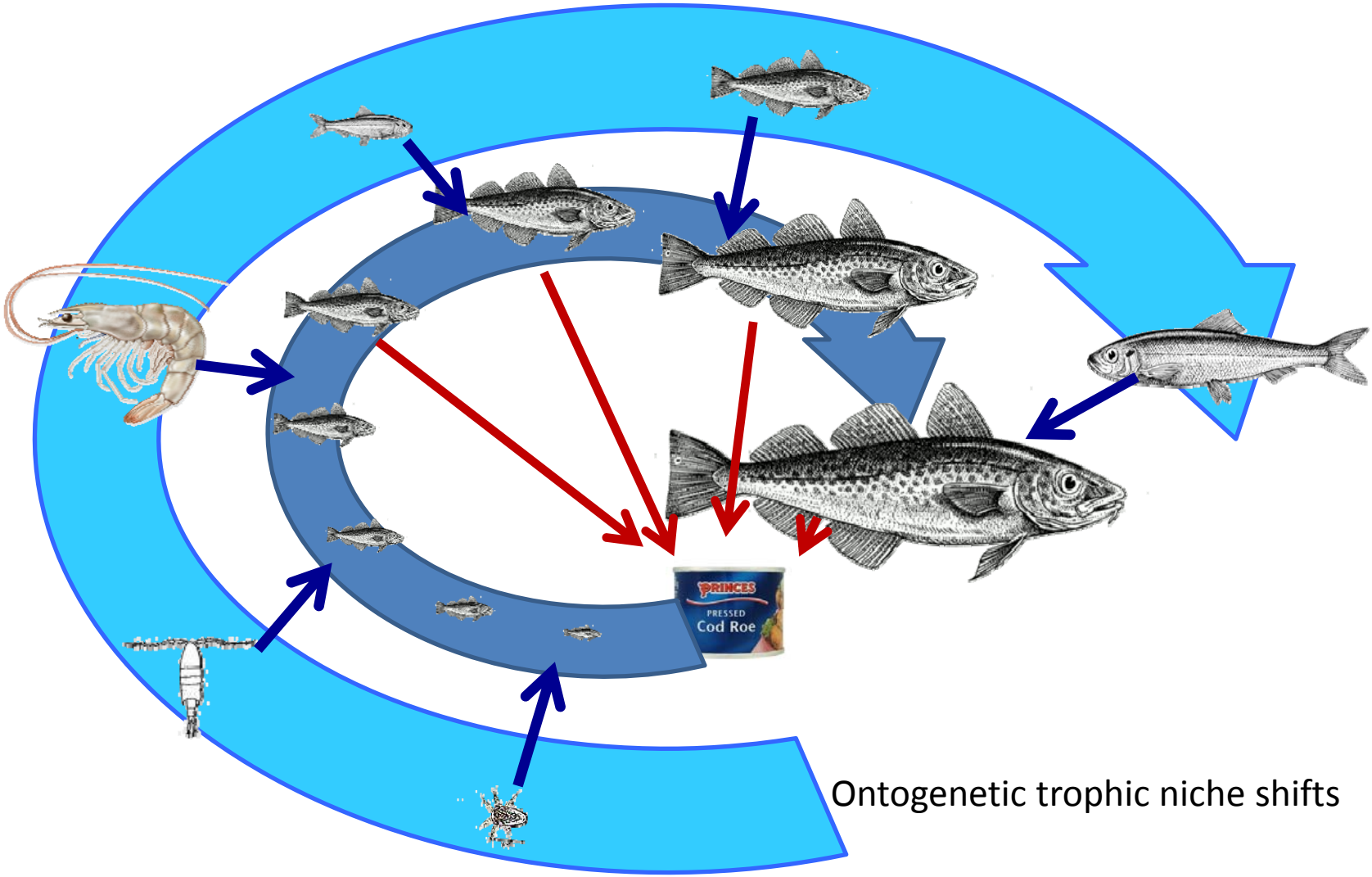
1) We do not need to remove *all* fish
2) We can get more protein out of the sea
3) Conflict between maximizing protein and profit
4) Conservation hardest for the largest species, and gives lower yield.

Tradeoffs between management objectives

Protein yield

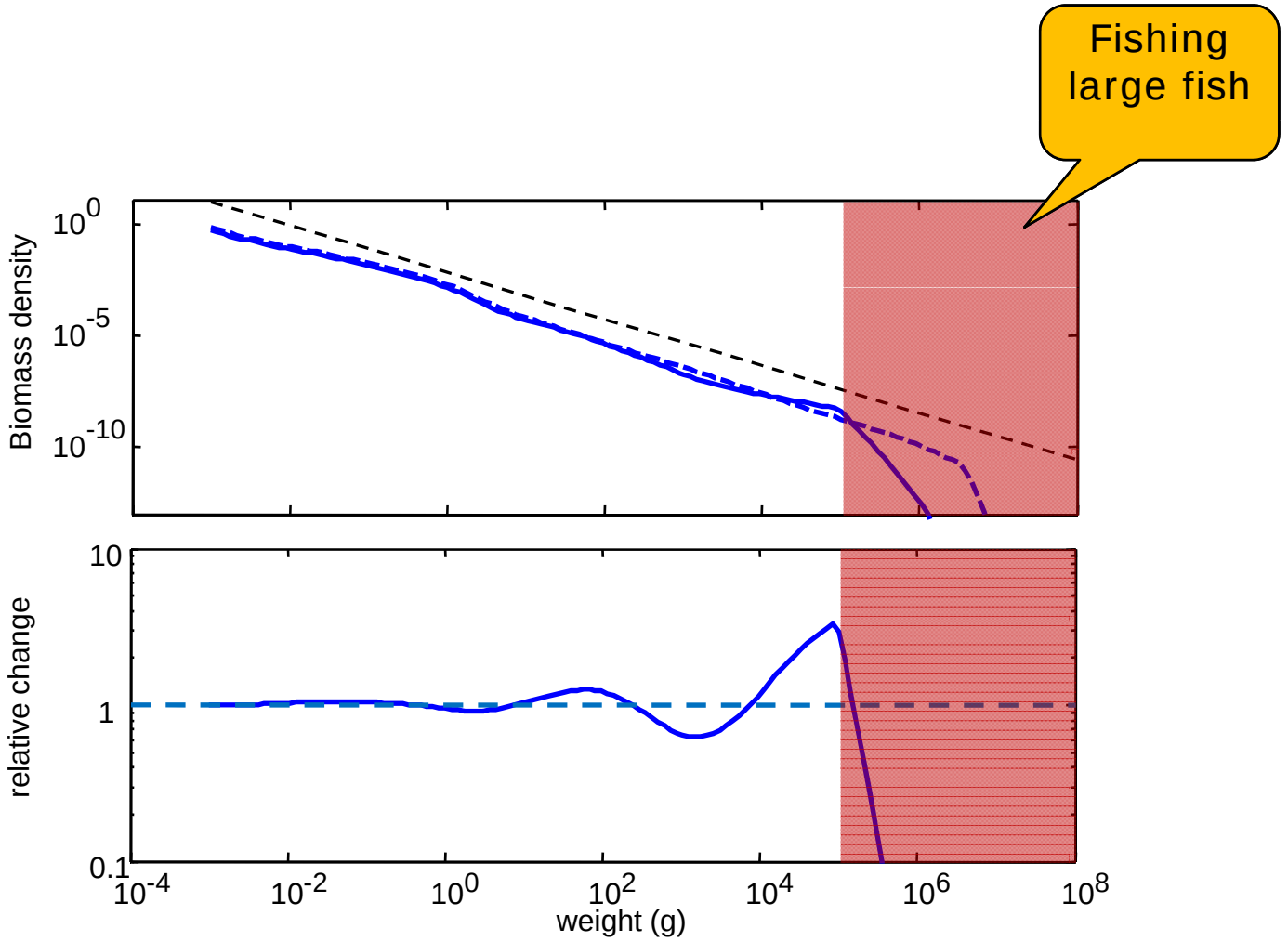
Rent

Maximize protein



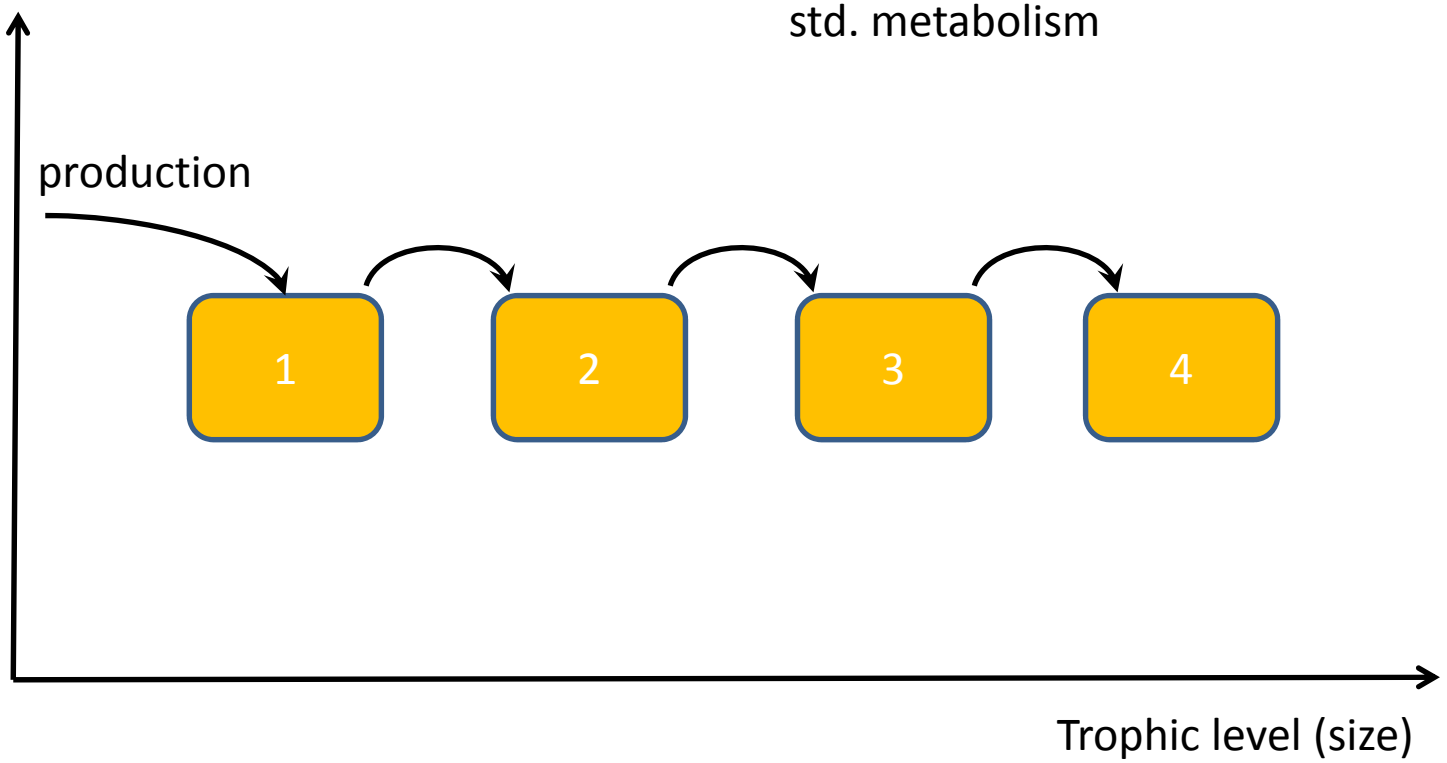
Ontogenetic trophic niche shifts

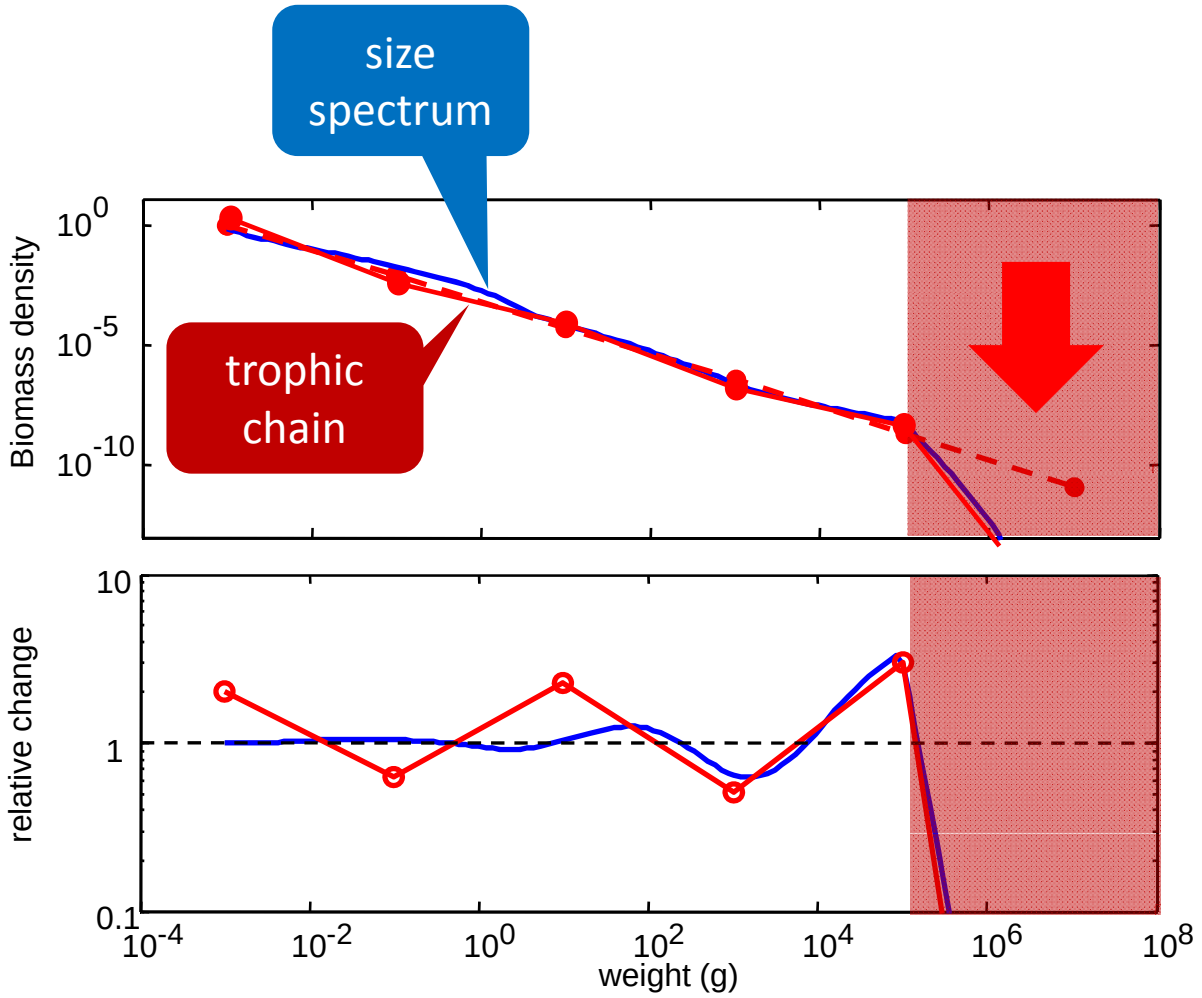
Community size spectrum model



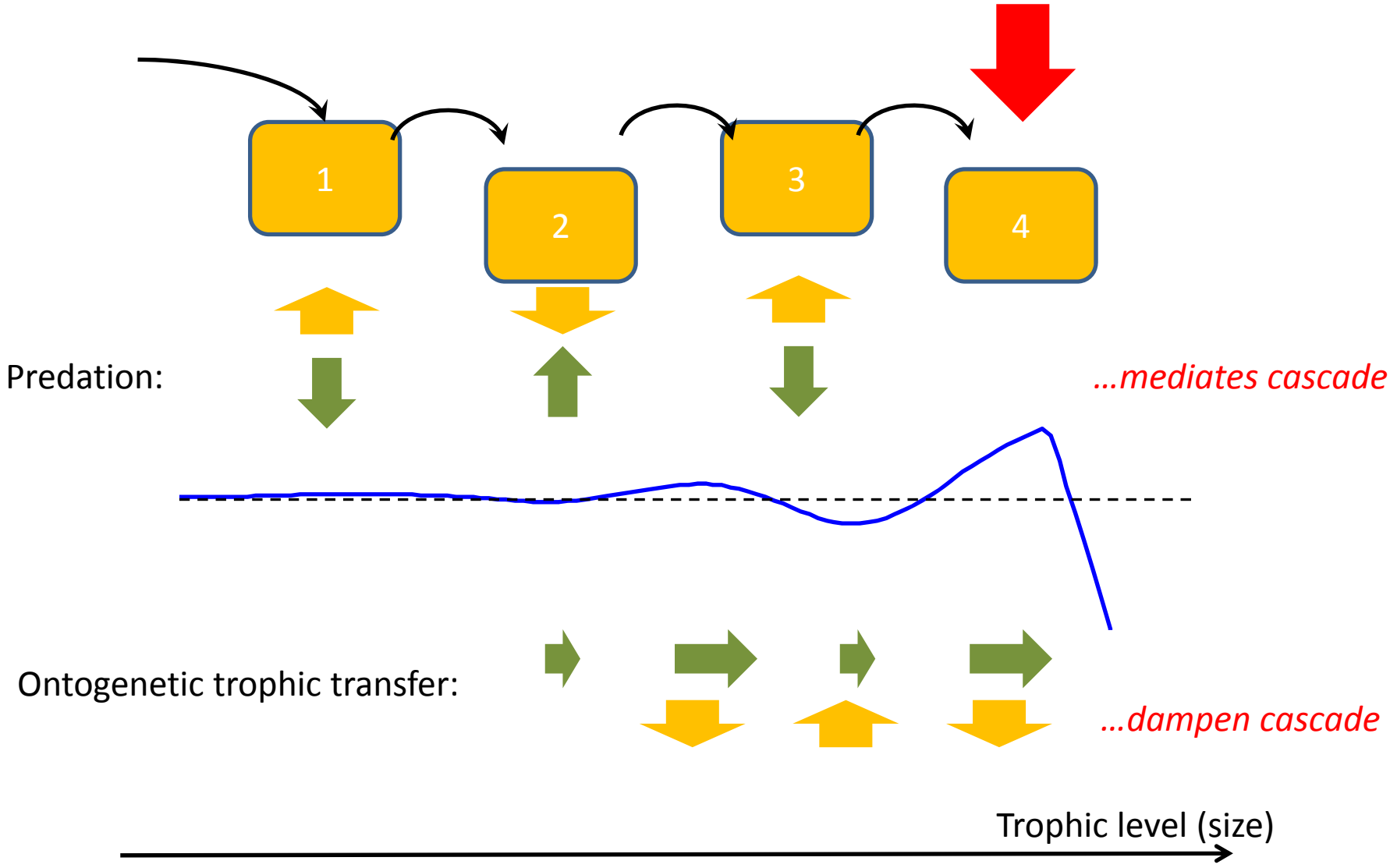
Does ontogenetic trophic niche shifts matter?

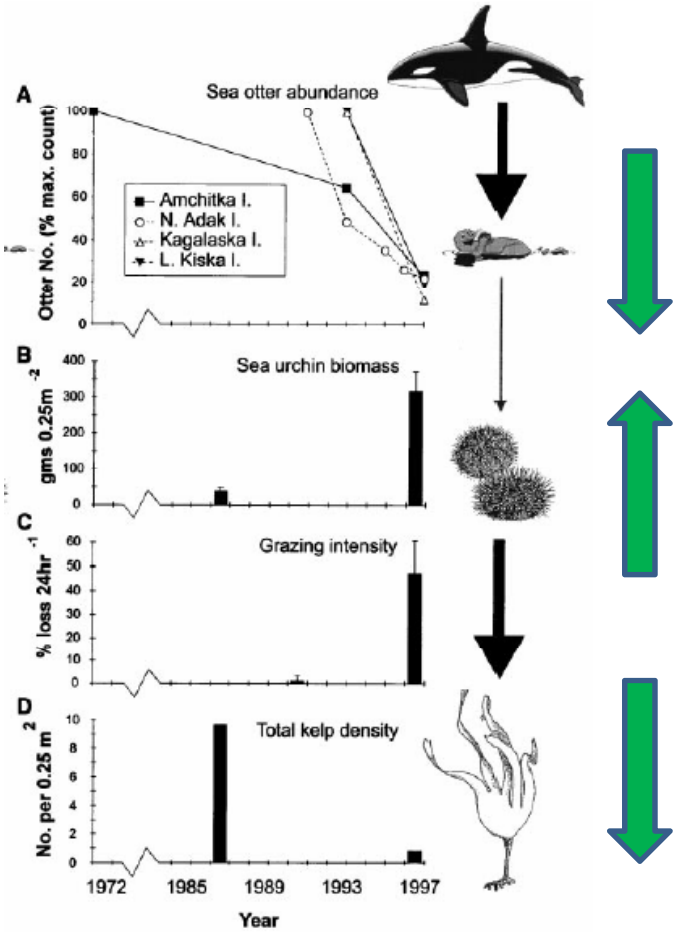
$$\frac{\dot{N}_i}{N_i} = \underbrace{\epsilon\gamma w_i^{q-1} w_{i-1} N_{i-1}}_{\text{reproduction rate}} - \underbrace{k w_i^{n-1}}_{\text{std. metabolism}} - \underbrace{\gamma w_{i+1}^{q} N_{i+1}}_{\text{predation losses}}$$



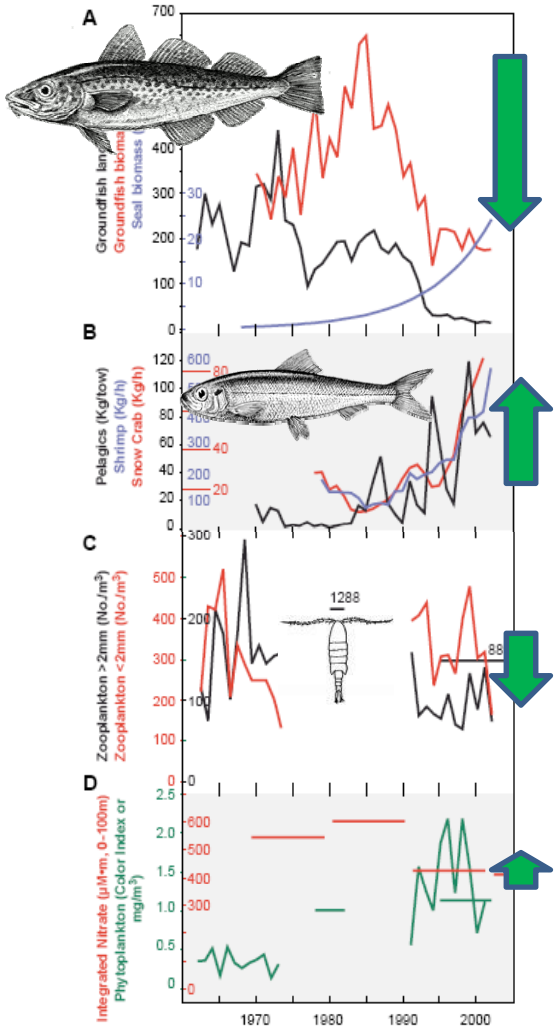

size
spectrum
trophic
chain
Biomass density
10^{0}
10^{-5}
10^{-10}
relative change
10
1
0.1
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
10^{6}
10^{8}
weight (g)

Why the difference?





Estes et al, Science (1998)



Cod biomass decreased by a factor 2

Large zooplankton decreased by a 30 %

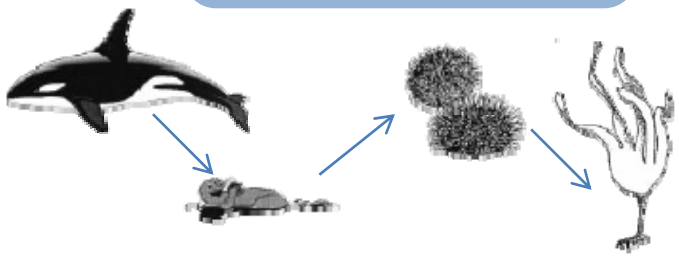
North-west Atlantic
Frank et al (2005)

Two kinds of ecosystems...

System

No ontogenetic trophic niche shift

Ontogenetic trophic niche shift



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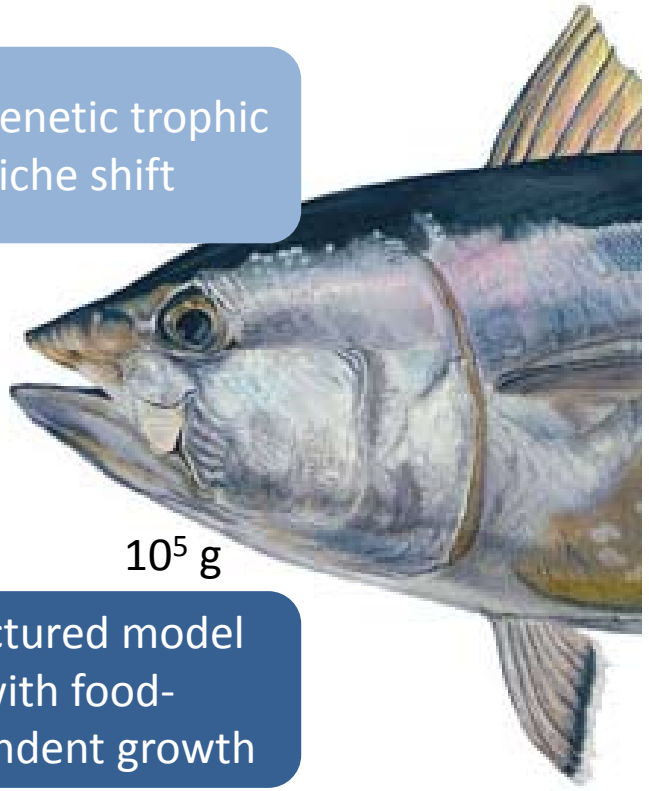


10^{-4} g

10^{5} g

Model

Unstructured food web

Structured model with food-dependent growth

Control

Global control

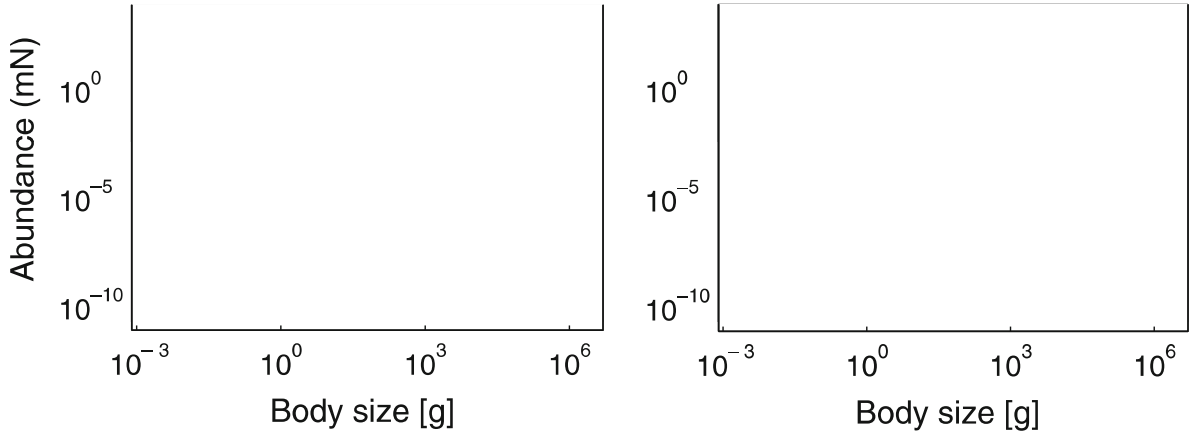
Local control

... two kinds of control

Stability of size spectra

Community model
(Benoit & Rochet, 2004)

Trait-based model
(Andersen & Beyer, 2006)



Trait-based model:

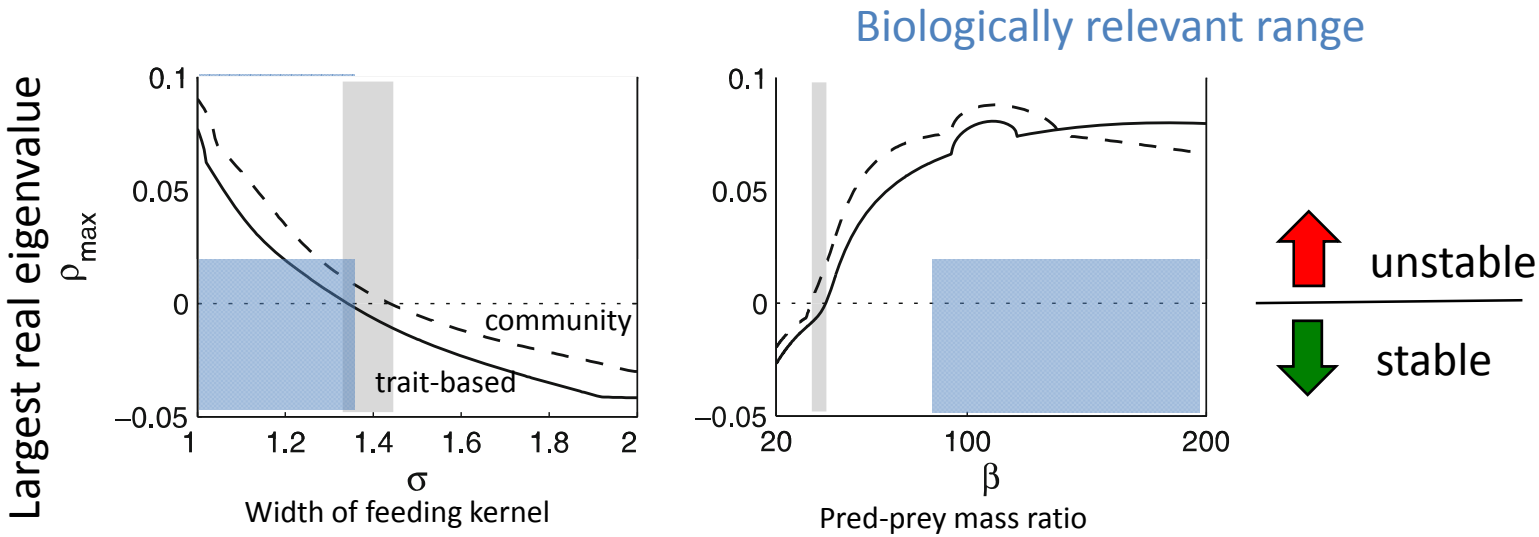
$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial w}\left[\left(\alpha\gamma w^{q}\int_{0}^{\infty} w_{p}\phi\left(\frac{w_{p}}{w}\right)N_{c}(w)dw_{p} - W_{\infty}^{n-1}w\right)N\right] = -N\int_{0}^{\infty}\gamma w^{q}\phi\left(\frac{w}{w'}\right)N_{c}dw'$$

Community model:

$$N_{c}(w) = \int_{w}^{\infty} N(w, W_{\infty})\,\mathrm{d}W_{\infty}$$

Stability analysis of linearized solution

Discretize equations -> equilibrium numerically -> Jacobian -> eigenvalues

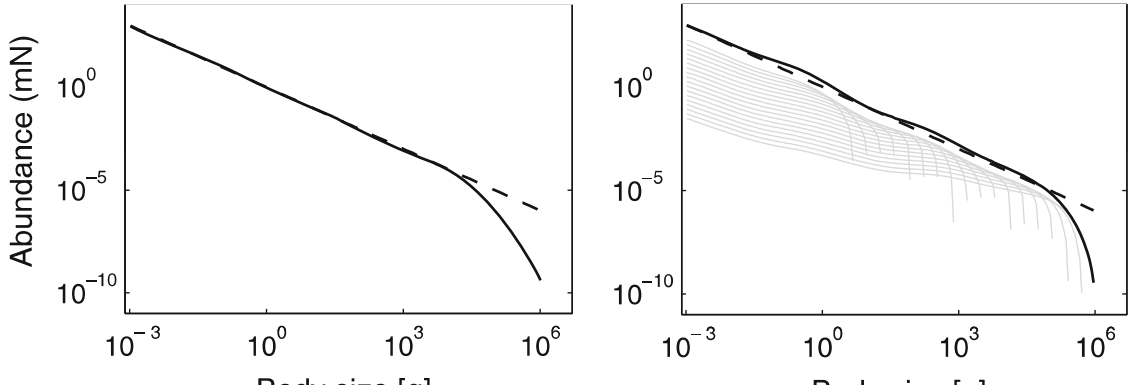


=> Both models are linearly unstable!

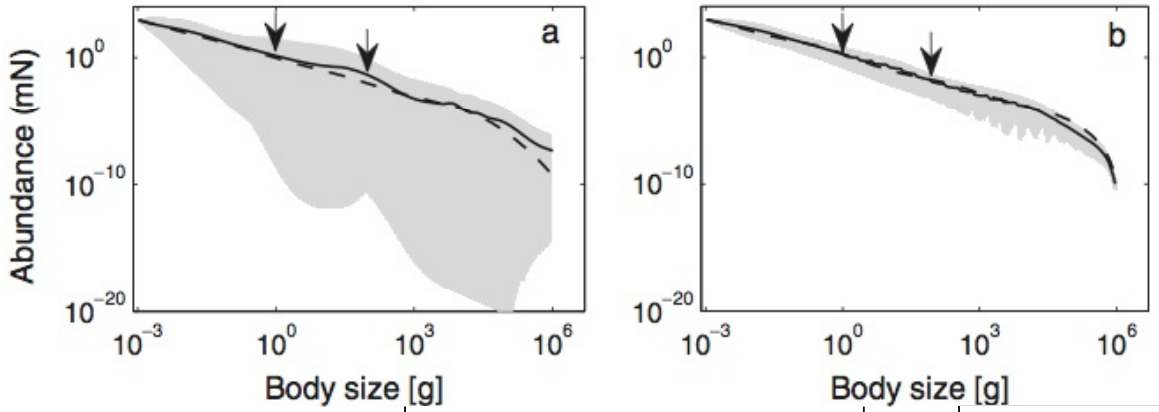
Community model
(Benoit & Rochet, 2004)

Trait-based model
(Andersen & Beyer, 2006)

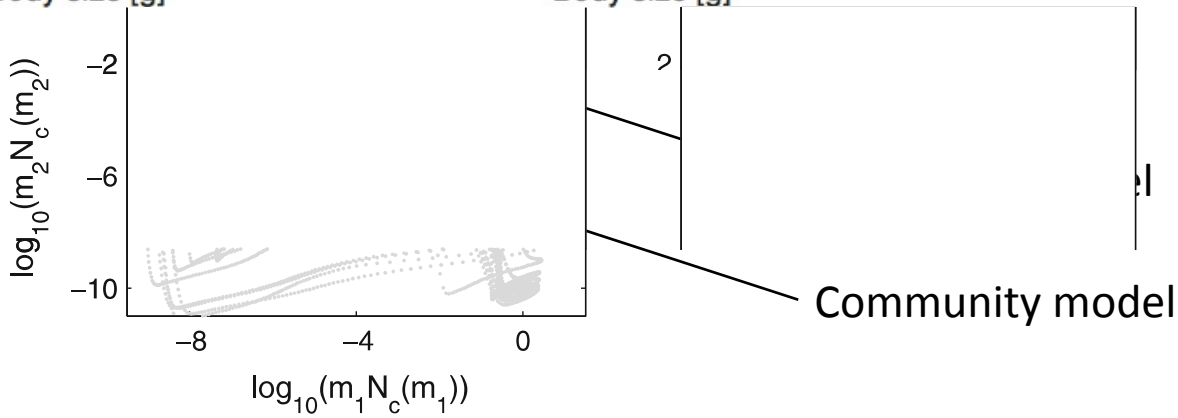
(Unstable) equilibrium solution



Average solution

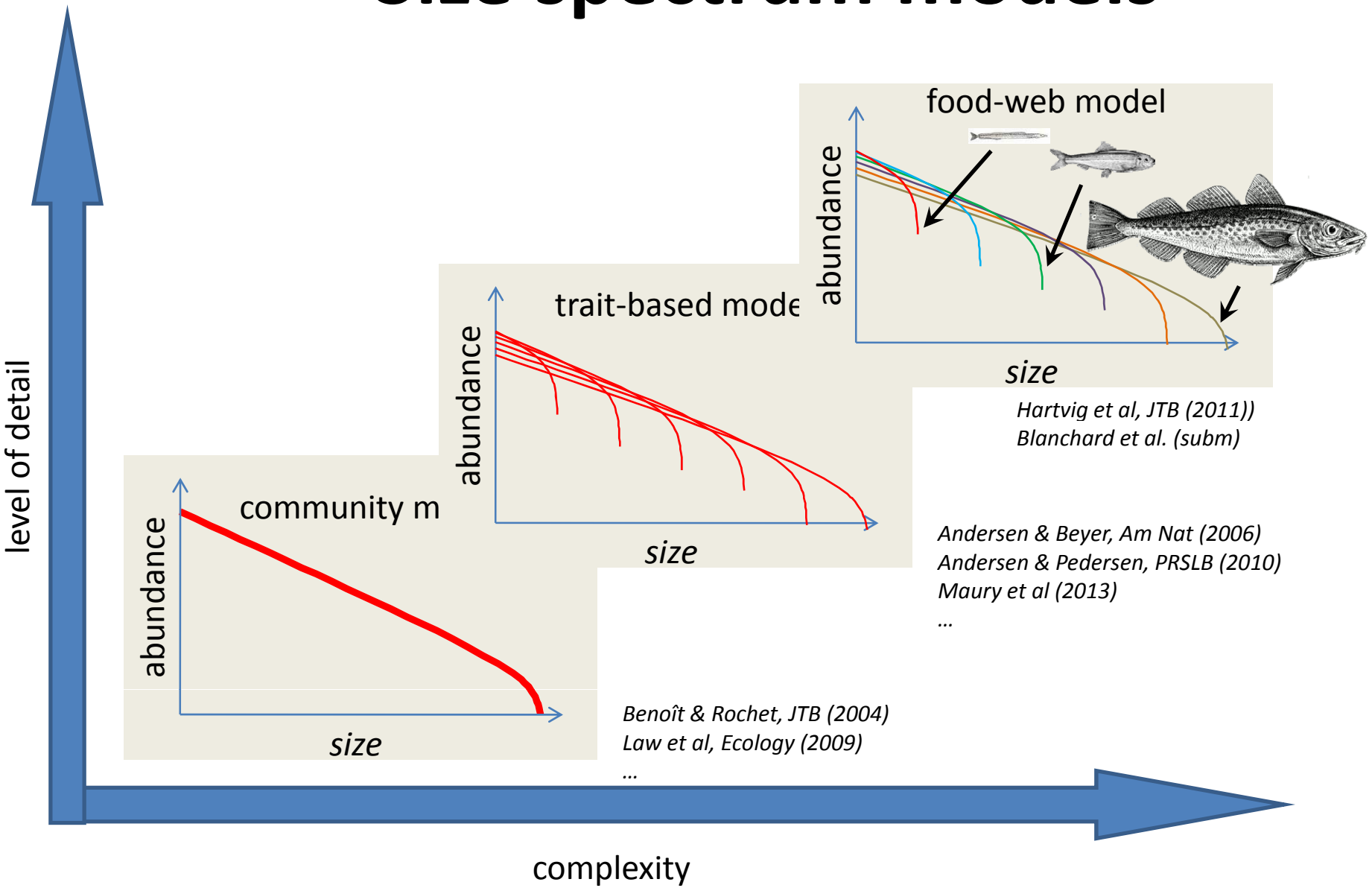


Phase portraits



Zhang et al, TE (2012)

Size spectrum models



Hartvig et al, JTB (2011))
Blanchard et al. (subm)

Andersen & Beyer, Am Nat (2006)
Andersen & Pedersen, PRSLB (2010)
Maury et al (2013)
…

Benoît & Rochet, JTB (2004)
Law et al, Ecology (2009)
…

spectrum.stockassessment.org

Size Spectrum Calculator

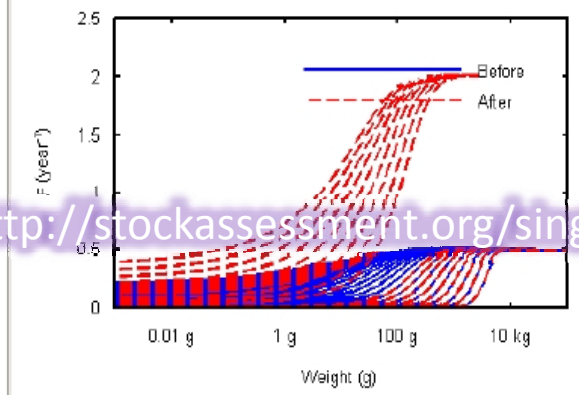
Calculate the expected ecosystem effect of a management plan involving changing the fishing effort on one aspect of the fish community. The fishing effort is divided on three groups of fish species:
- Small species ("forage fish"): asymptotic weight less than 100 g
- Medium species ("small pelagics"): asymptotic weight between 100 g and
- Large species ("large demersals/pelagics"): asymptotic weight larger than 4 kg.

Input parameters

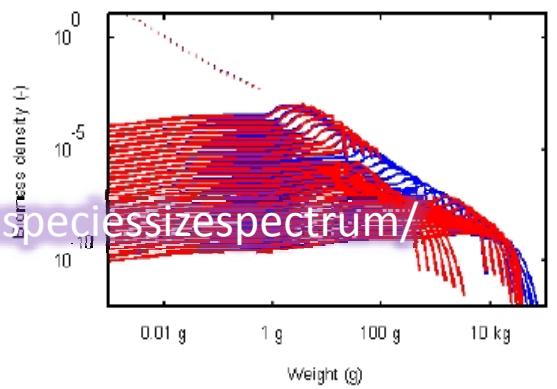
	Before change		After change	
F_{small}	0.5	$year^{-1}$	0.5	$year^{-1}$
F_{medium}	0.5	$year^{-1}$	2	$year^{-1}$
F_{large}	0.5	$year^{-1}$	0.5	$year^{-1}$

Calculate

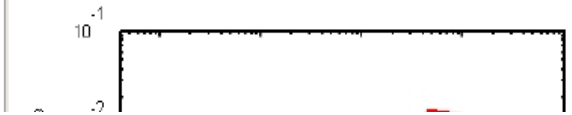
Results

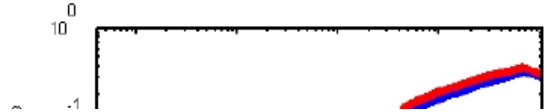


The fishing mortality as a function of individual size for the base case (before the change) in blue and after the change in red. Each line correspond to an asymptotic size class.



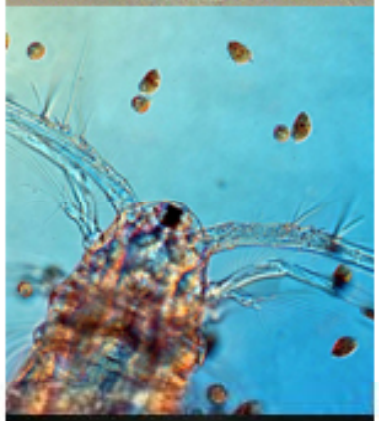
Size spectra for 18 asymptotic size classes as a function of individual weight. The dotted lines in the top left corner are the resource spectra.





Check also: http://stockassessment.org/singlespeciessizespectrum/

Ocean Life
Centre for Ocean Life
VKR Centre of Excellence



Centre for Ocean Life

How will life in the oceans respond to environmental change? With our increasing awareness and concern for human impact on the marine environment and its role in regulating global climate, the need for predicting the future of life in the ocean becomes pressing. The goal of the centre is to develop a fundamental understanding and predictive capability of marine ecosystems.

The centre brings together biologists, physicist, chemists, and mathematicians from three Danish universities, funds PhD and postdoctoral fellows, offers PhD summer schools, international workshops, and operates a Researcher Visitors Centre.

The centre opened January 1, 2012.

Centre management team

Chair: Thomas Kiørboe
Deputy chair: Ken H. Andersen
Administrative management: Kirsten Thomsen

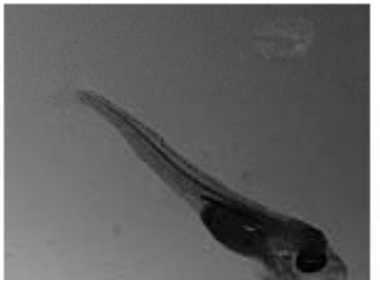
VILLUM FONDEN

News & activities

International workshop
26-28th of August 2013
International workshop on Trait based approaches to ocean life
At The Royal Danish Academy of Sciences and Letters
HC Andersens Boulevard 35, Copenhagen, Denmark
Now open for applications

Annual meeting
10-11th of December 2012
At Søminestationen, Holbæk
Read more

See all News & activities



Questions:

- Which pattern of F generates the highest yield?
- Which pattern conserves biomass?
- What happens if we do not fish forage fish?
- Which species group tolerates the highest F?