Fish bioenergetics, introduction

Compiled by Dan Galeriu for EMRAS II WG7

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Giovanni di Paolo (15th cent.), for Dante's Divine Comedy

What is bioenergetics?

The study of the processing of energy by living systems, *at any level of biological organization.*

In fisheries science, we typically

- consider the bioenergetics of individuals
- use this to develop budgets for populations
- make projections about fish production in particular areas (e.g., Lake Ontario salmon production)

Fish bioenergetics is a subset of a much broader field called **ecological energetics**

What is Bioenergetics?

"…..the study of the flow and transformation of energy in and between living organisms and between living organisms and their environment"

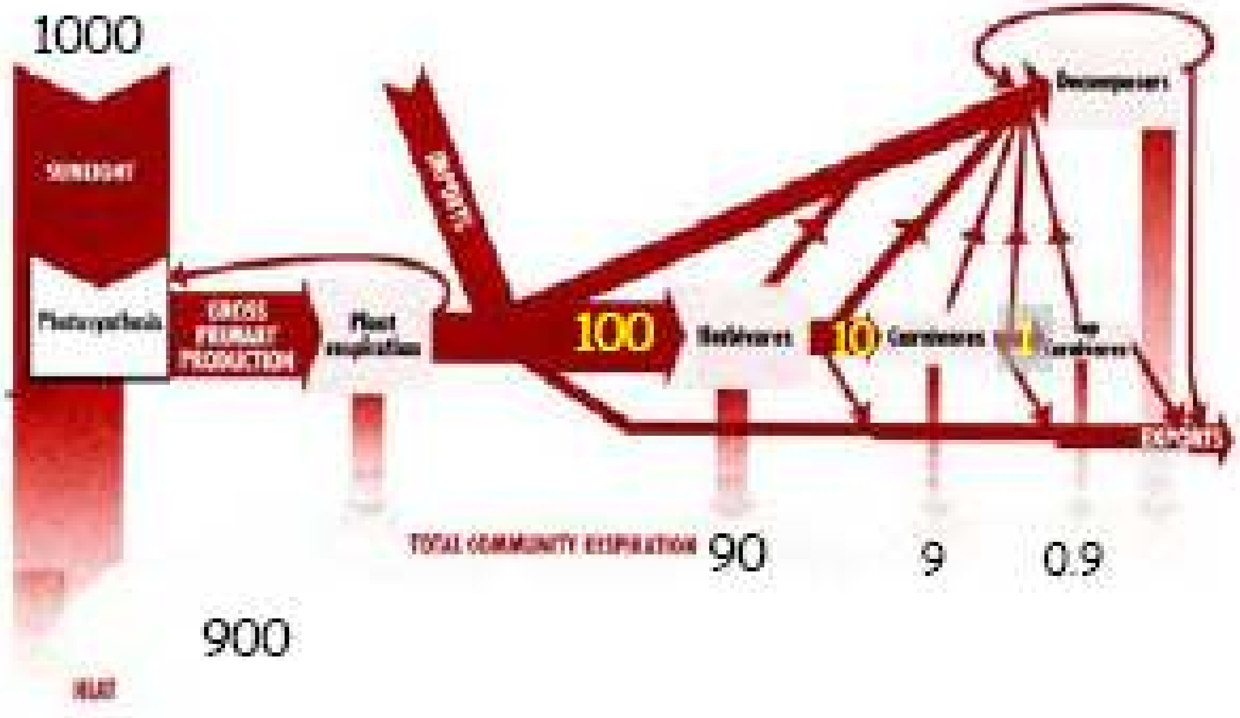
Review: the first two Laws of Thermodynamics

1. Energy and matter cannot be created or destroyed, but they can be changed from one form to the other

2. *Any transformation of energy or matter results in some loss of "useful" energy – in other words, no energetic process is 100% efficient*

(entropy, the tendency toward disorder, is like an 'energy tax')

Hypothetical energy flow through a food chain



Source: Dodson, 1998

Energy budgets:

- are like bank accounts: inputs (like deposits), outputs (like withdrawals), storage (like your bank balance), and growth (like interest)

- has to balance!

  Inputs = Outputs + Growth

- should always use the *same* units (like currency)

- examples of typical units: calories or joules [energy], carbon, or even biomass (grams)

Bioenergetics ~ Economics

<u>Consumption = Metabolism + Waste + Growth</u>

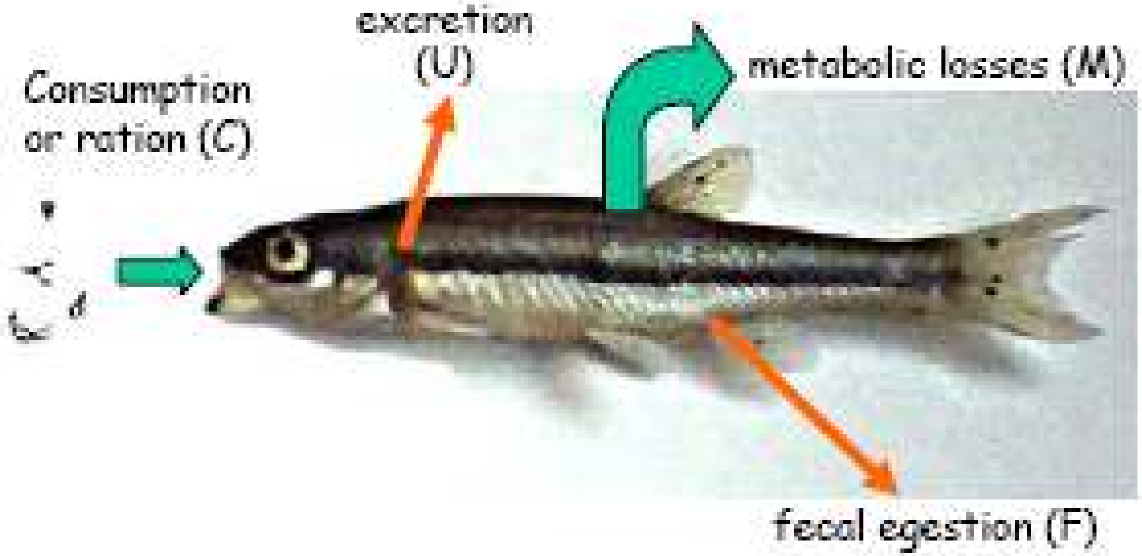
Consumption = Income

Metabolism = Rent

Wastes & Losses = Taxes

Growth = Savings and Investments

Energy budget for a fish:



What is left over?

Model Components:

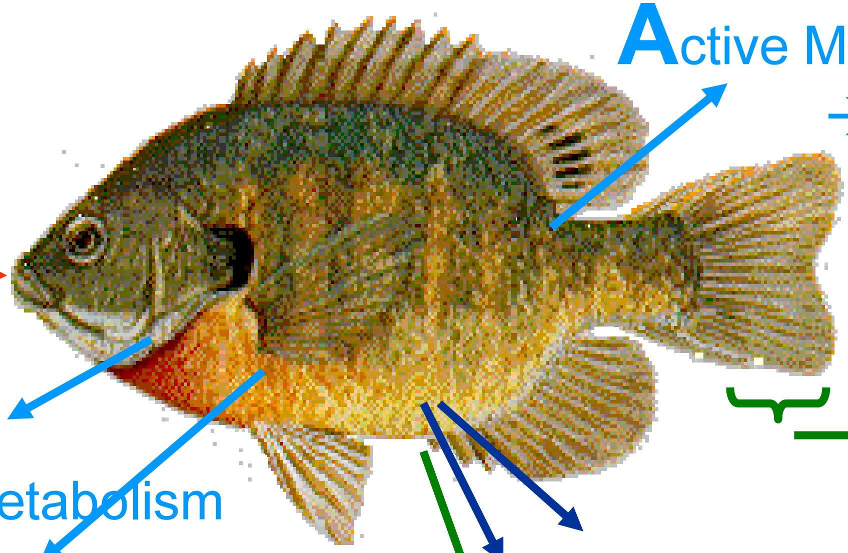
Consumption

Respiration

→ Basal Metabolism

Specific Dynamic Action

→ Costs from digestion



Active Metabolism

→ Costs from activity

Δ Biomass

→ Growth

Egestion-**F** & Excretion -**U**

Gonads

→Reproduction

$$C = (R + A + S) + (F + U) + (\Delta B + G)$$

Typical Energy Budgets Differ for Carnivores & Herbivores:

Normalized Percentages	Consumption	Respiration		Waste		Growth
Carnivore	100 =	44	+	27	+	29
Herbivores	100 =	37	+	43	+	20

Green Sunfish

Largescale Stoneroller

Muskellunge

Bioenegetics Model

$$\frac{dW}{W\cdot\ dt}=[C-(R+SDA+F+E+P)]$$

W:wet weight(g), t:time(day),
C:consumption (gprey/gfish/day),
R:respiration or losses through metabolism (gprey/gfish/day),
SDA: specific dynamic action or losses due to energy costs of digesting food (gprey/gfish/day),
F:egestion or losses due to feces (gprey/gfish/dday),
E:excretion or losses of nitrogenous excretory wastes (gprey/gfish/dday),
P:egg production or losses due to reproduction (gprey/gfish/d)

★Foods of saury are ＺＳ，ＺＬ，ＺＰ with selective function

(VENFISH, 2002 PICES MODEL/REX TASK TEAM, 伊藤ら2002)

$$\text{(2.1.1)} \quad \frac{dW}{dt} = \left[C - (R + S + F + E)\right] \cdot \frac{CAL_z}{CAL_f} \cdot W$$

consumption

NEMURO

$$C = C_i \cdot f_c(T)$$

$$C_i = \sum_{j=1}^{n} C_j$$

$$C_j = \frac{C_{MAX} \cdot \frac{PD_{ij} \cdot v_{ij}}{K_{ij}}}{1 + \sum_{k=1}^{n} \frac{PD_{ik} \cdot v_{ik}}{K_{ik}}}$$

$$C_{MAX} = a_c \cdot W^{b_c}$$

$$f_c(T) = gcta \cdot gctb$$

where

$$tt5 = \frac{1}{(te2 - te1)}$$

$$t5 = tt5 \cdot a\log\left[0.98 \cdot \frac{(1.0 - xk1)}{(0.02 \cdot xk1)}\right]$$

$$t4 = e^{[t5 \cdot (T - te1)]}$$

$$tt7 = \frac{1}{(te4 - te3)}$$

$$t7 = tt7 \cdot a\log\left[0.98 \cdot \frac{(1.0 - xk4)}{(0.02 \cdot xk4)}\right]$$

$$t6 = e^{[t7 \cdot (te4 - T)]}$$

PD_{ij} :density of prey type j (g wet weight/m^3),

v_{ij} :vulnerability of prey type *j* to predator *i*

K_{ij} :half saturation constant (g wet weight/m^3),

C consumption rate (g/g/d),

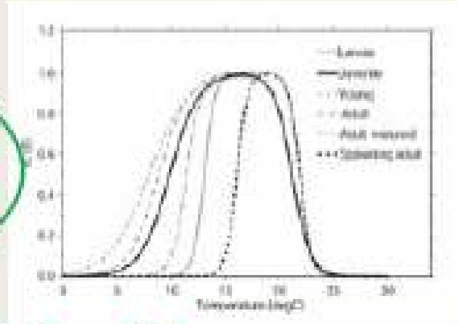
C_{MAX} :maximum consumption rate (g/g/d),

$f_c(T)$:temperature dependence function for consumptio

i predator type

$$gcta = \frac{(xk1 \cdot t4)}{(1.0 + xk1 \cdot (t4 - 1.0))}$$

$$gctb = \frac{(xk4 \cdot t6)}{(1.0 + xk4 \cdot (t6 - 1.0))}$$



Physical model

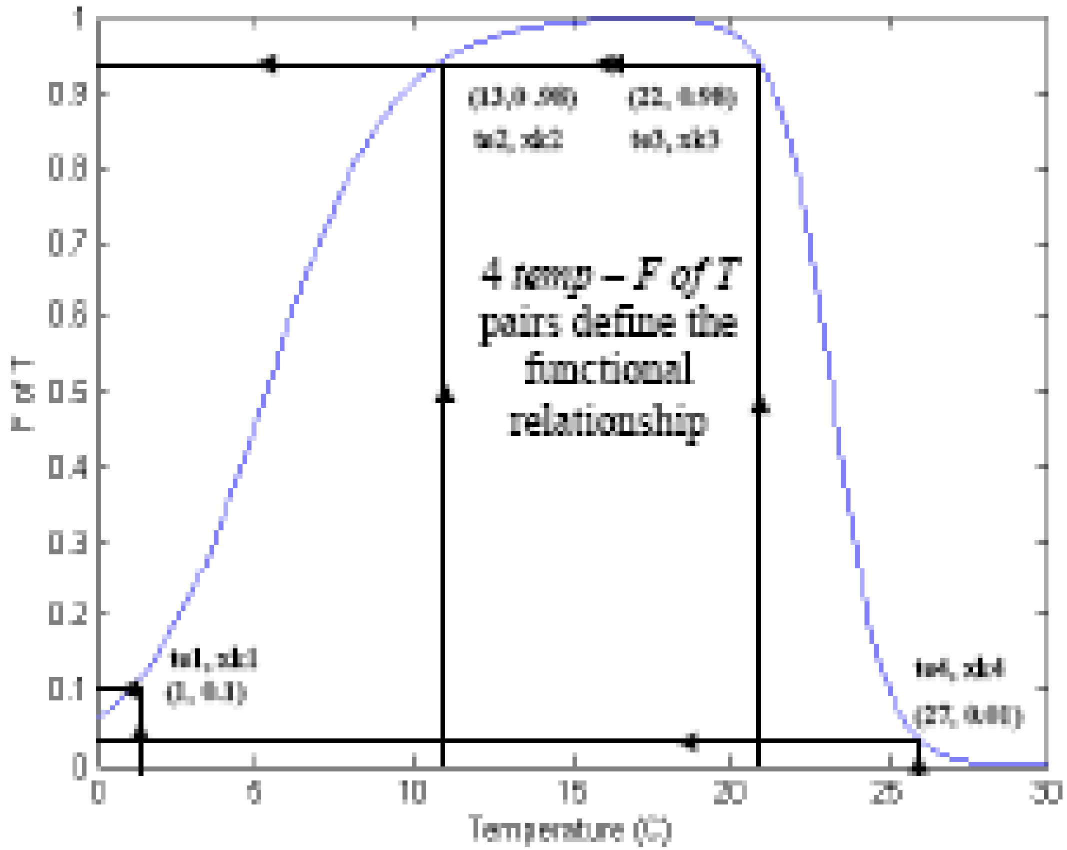
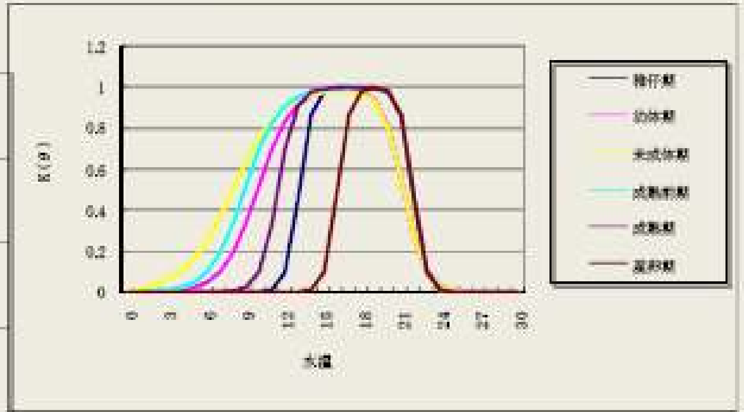


Fig. 2.1.2 Example of the Thornton and Lessem (1978) temperature adjustment curve for a theoretical set of parameters.

Temperature function

stage	*period*
1.larvae	1101-1215
2.juvenile	1216-0401
3.young	0402-0502
4.Pre mature	0502-0702
5.mature	0703-0903
6.spawning	0904-1031



温度とステージ				
	te1	te2	te3	te4
STAGE1	12	15	18	23
STAGE2	7	15	18	23
STAGE3	4	15	18	23
STAGE4	6	14	20	23
STAGE5	10	14	20	23
STAGE6	15	18	20	23

Suitable temp.

$$f(T) = V^X \cdot e^{[X \cdot (1-V)]},$$

where

$$V = (\mathrm{CTM} - T)/(\mathrm{CTM} - \mathrm{CTO});$$

$$X = \{Z^2 \cdot [1 + (1 + 40/Y)^{0.5}]^2\}/400,$$

$$Z = \log_e(\mathrm{CQ}) \cdot (\mathrm{CTM} - \mathrm{CTO}), \quad \text{and}$$

$$Y = \log_e(\mathrm{CQ}) \cdot (\mathrm{CTM} - \mathrm{CTO} + 2).$$

The temperature dependence function for respiration is a simple exponential relationship given by

$$(2.1.8)\quad f_R(T) = e^{(c_R \cdot T)}$$

where c_R approximates the Q_{10} (the rate at which the function increases over relatively low water temperatures).

Activity is a power function of body weight conditioned on water temperature and is given by

$$(2.1.9)\quad activity = e^{(d_R \cdot U)}$$

where U is swimming speed in cm·s^{-1} and d_R is a coefficient relating swimming speed to metabolism. Swimming speed is calculated as a function of body weight and temperature using

$$(2.1.10)\quad U = a_A \cdot W^{b_A} \cdot e^{(c_A \cdot T)}$$

where $a_{A}=$ 3.9, b_A = 0.13 and c_A=0.149 if T <9.0 °C
and $a_{A}=$ 15.0, b_A = 0.13 and c_A=0.0. if T $\geq$9.0 °C

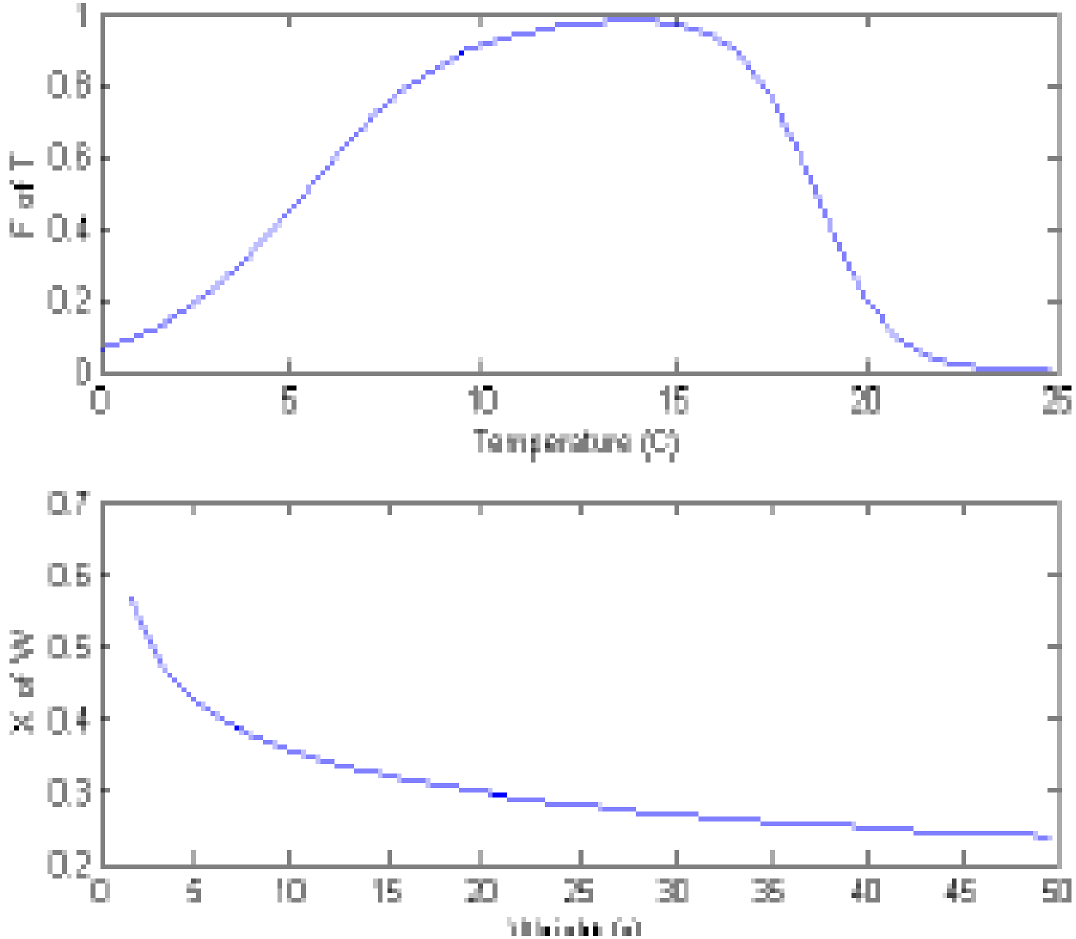
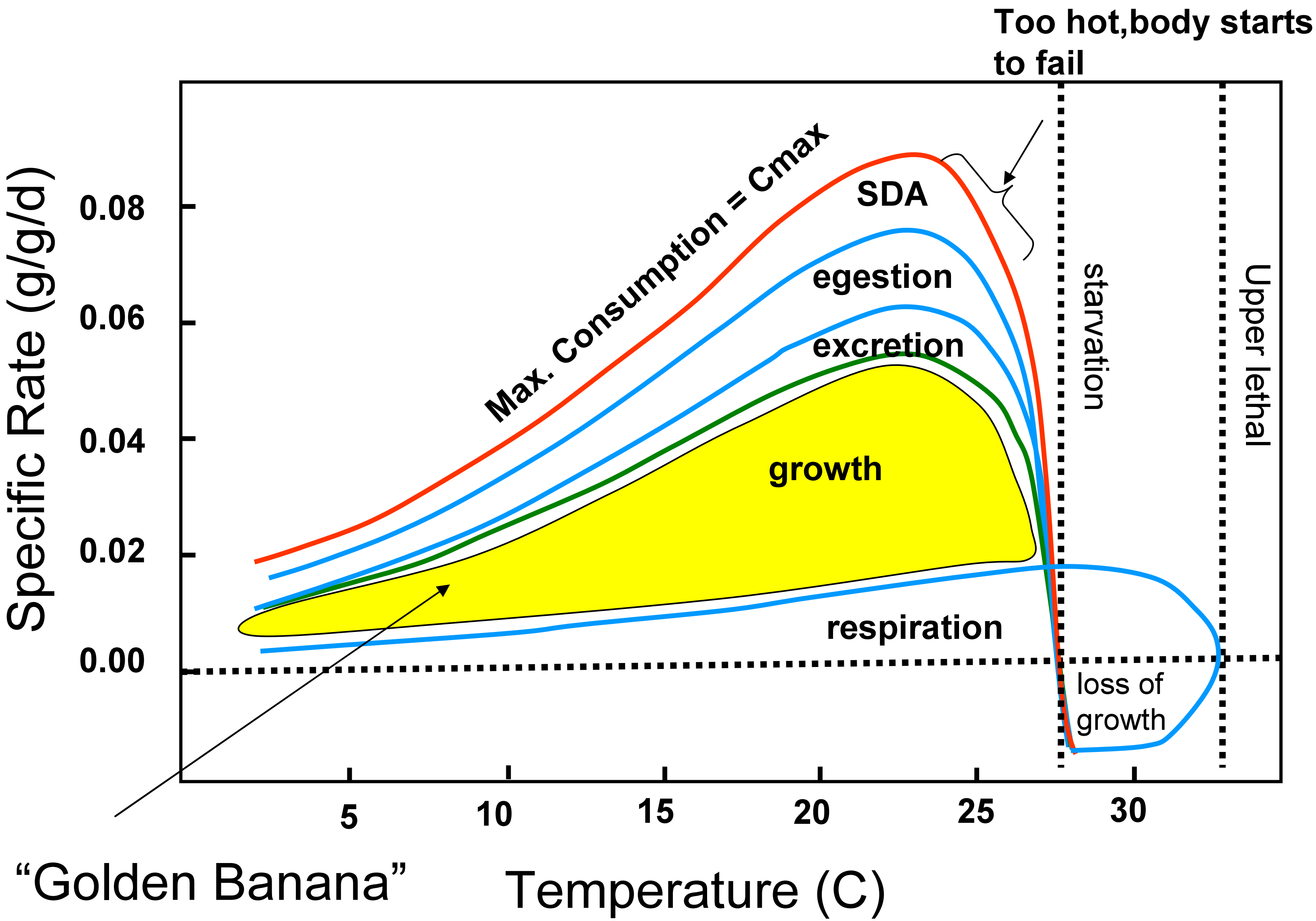


Fig. 2.1.1 Relationship between consumption and temperature from equation 2.1.4 (upper panel) and consumption and weight from equation 2.1.3 (lower panel).

All processes are temp. and size dependent



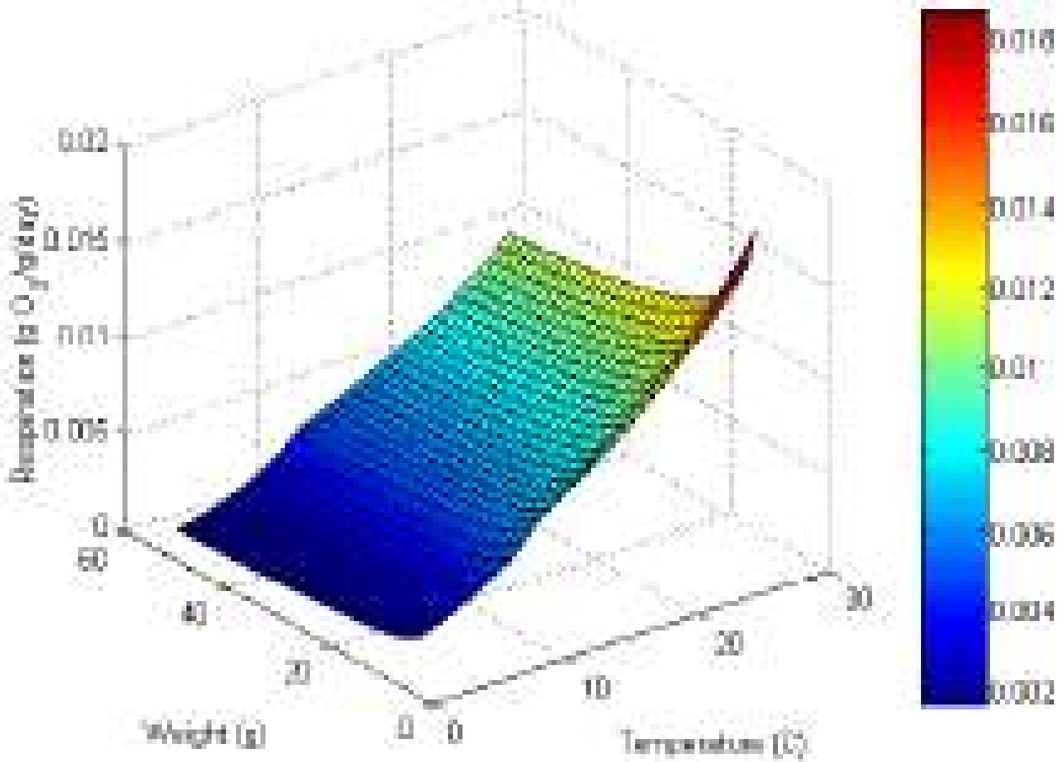


Fig. 2.1.5 Relationship between standard respiration, weight and temperature from equation 2.1.5.

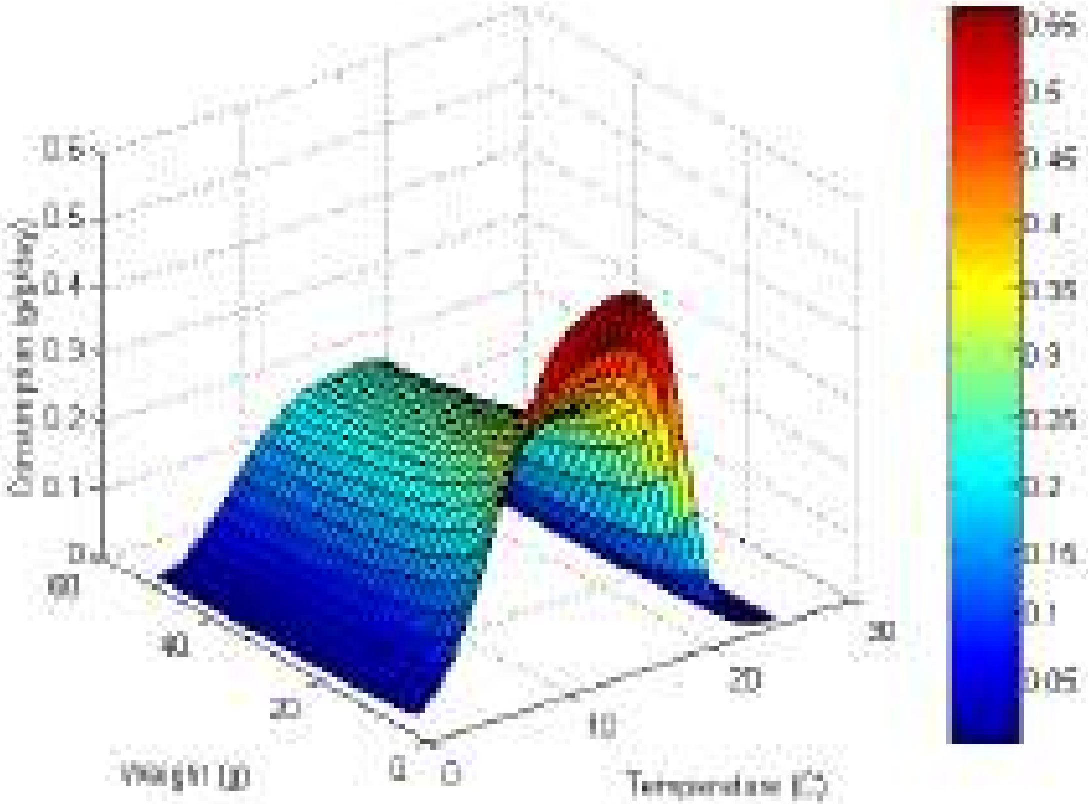


Fig. 2.1.4 Plot of the consumption, temperature and weight relationships from equation 2.1.2.

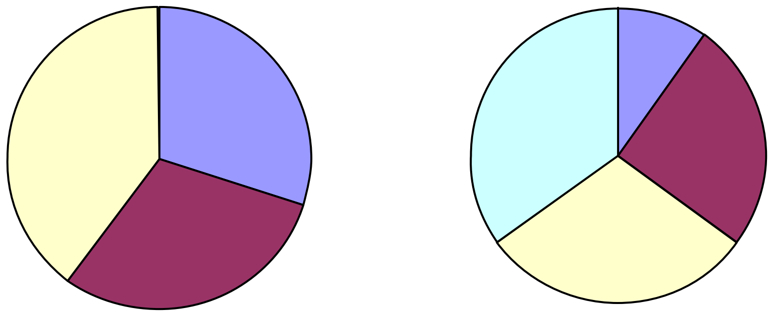
What else do we need to run the model?

Temperatures where fish live…

- alewife - 20° C
- bluegill - 29° C
- coho salmon - 15° C
- largemouth bass – 27.5° C
- muskellunge - 26° C
- northern pike - 24° C
- rainbow smelt - 13° C
- rainbow trout - 20° C
- striped bass – 21.6° C
- walleye - 22° C
- yellow perch - 26° C
- smallmouth bass – 29 ° C
- sea lamprey - 18° C
- chinook salmon - 15° C

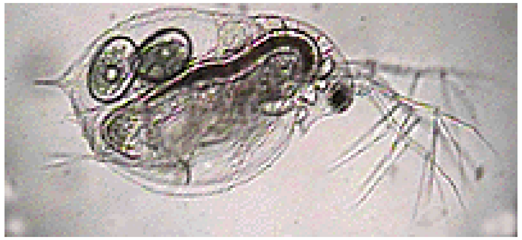
What do we need to run the model?

What a fish eats …



What do we need to run the model?

Prey and Predator Energy Densities …



Zooplankton – 2513 j/g wet mass

Snails – 18000 j/g dry mass

Crayfish – 3766 j/g wet mass

Yellow Perch – 5000 j/g dry mass

Leech – 24000 j/g dry mass

Alewife – 7225 j/g wet mass

What do we need to run the model?

Basic physiological parameters…

- Egestion (size/temp dependent) → F
- Excretion (size/temp dependent) → U
- Specific Dynamic Action → SDA
- Basal Metabolism → R
- Active Metabolism → A

Where do we get all these….?

- We do painstakingly difficult lab experiments (imagine having to measure fish excrement or…)
- We steal them, I mean “borrow” them!
- Species borrowing is common, it can cause problems
- Should evaluate and test if borrowing is appropriate