Fish bioenergetics, introduction

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WG7
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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

1000

100

90

9

0.9

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

Consumption = Income

Metabolism = Rent

Wastes & Losses = Taxes

Growth = Savings and Investments
Energy budget for a fish:

Consumption or ration (C)

excretion (U)

metabolic losses (M)

fecal egestion (F)

What is left over?
Model Components:

\[
C = (R + A + S) + (F + U) - (\Delta B + G)
\]
Typical Energy Budgets Differ for Carnivores & Herbivores:

<table>
<thead>
<tr>
<th>Normalized Percentages</th>
<th>Consumption</th>
<th>Respiration</th>
<th>Waste</th>
<th>Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carnivore</td>
<td>100 =</td>
<td>44</td>
<td>27</td>
<td>29</td>
</tr>
<tr>
<td>Herbivores</td>
<td>100 =</td>
<td>37</td>
<td>43</td>
<td>20</td>
</tr>
</tbody>
</table>

Largescale Stoneroller

Green Sunfish

Muskellunge
Bioenergetics Model

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

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

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

(VENFISH, 2002 PICES MODEL/REX TASK TEAM, 伊藤ら2002)
(2.1.1) \( \frac{dW}{dt} = \left[ C - (R + S + F + E) \right] \cdot \frac{CAL_z}{CAL_f} \cdot W \)
consumption

\[ C - C_i \cdot f_i(T) \]

\[ C_i = \sum_{j=1}^{n} C_j \]

\[ C_j = \frac{P_{D_j} \cdot V_0}{K_s} \]

\[ C_{\text{max}} = \frac{P_{D_j} \cdot V_0}{K_s} \times \frac{1}{1 + \sum_{k=1}^{n} \frac{P_{D_k} \cdot V_k}{K_k}} \]

\[ C_{\text{max}} = a \cdot W^h \]

where

\[ f_i(T) = gcta \cdot gctb \]

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

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

PDj : density of prey type j (g wet weight/m²·s).

v0 : vulnerability of prey type j to predator i

Ks : half saturation constant (g wet weight/m²·s).

c : consumption rate (g/g/d).

Cmax : maximum consumption rate (g/g/d).

fi(T) : temperature dependence function for consumption

i : predator type

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

<table>
<thead>
<tr>
<th>stage</th>
<th>period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. larvae</td>
<td>1101-1215</td>
</tr>
<tr>
<td>2. juvenile</td>
<td>1216-0401</td>
</tr>
<tr>
<td>3. young</td>
<td>0402-0502</td>
</tr>
<tr>
<td>4. Premature</td>
<td>0502-0702</td>
</tr>
<tr>
<td>5. mature</td>
<td>0703-0903</td>
</tr>
<tr>
<td>6. spawning</td>
<td>0904-1031</td>
</tr>
</tbody>
</table>

### Table

<table>
<thead>
<tr>
<th>stage</th>
<th>te1</th>
<th>te2</th>
<th>te3</th>
<th>te4</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAGE1</td>
<td>12</td>
<td>15</td>
<td>18</td>
<td>23</td>
</tr>
<tr>
<td>STAGE2</td>
<td>7</td>
<td>15</td>
<td>18</td>
<td>23</td>
</tr>
<tr>
<td>STAGE3</td>
<td>4</td>
<td>15</td>
<td>18</td>
<td>23</td>
</tr>
<tr>
<td>STAGE4</td>
<td>6</td>
<td>14</td>
<td>20</td>
<td>23</td>
</tr>
<tr>
<td>STAGE5</td>
<td>10</td>
<td>14</td>
<td>20</td>
<td>23</td>
</tr>
<tr>
<td>STAGE6</td>
<td>15</td>
<td>18</td>
<td>20</td>
<td>23</td>
</tr>
</tbody>
</table>
\[ f(T) = V^X \cdot e^{[X \cdot (1 - V)]}, \]

where

\[ V = (\text{CTM} - T)/(\text{CTM} - \text{CTO}); \]
\[ X = \{Z^2 \cdot [1 + (1 + 40/Y)^{0.5}]^2\}/400, \]
\[ Z = \log_e(\text{CQ}) \cdot (\text{CTM} - \text{CTO}), \quad \text{and} \]
\[ Y = \log_e(\text{CQ}) \cdot (\text{CTM} - \text{CTO} + 2). \]
The temperature dependence function for respiration is a simple exponential relationship given by

\[(2.1.8) \quad f_R(T) = e^{(c_R T)}\]

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

\[(2.1.9) \quad \text{activity} = e^{(d_R U)}\]

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

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

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

- Specific Rate (g/g/d)
- 0.08 0.06 0.04 0.02 0.00
- 5 10 15 20 25 30
- Temperature (°C)

- Growth
- SDA
- Egestion
- Excretion
- Max. Consumption = Cmax
- Respiration
- Loss of growth
- Upper lethal
- Starvation
- Too hot, body starts to fail

“Golden Banana”

Temperature (°C)
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
- **Leech** – 24000 j/g dry mass
- **Snails** – 18000 j/g dry mass
- **Crayfish** – 3766 j/g wet mass
- **Alewife** – 7225 j/g wet mass
- **Yellow Perch** – 5000 j/g dry 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