Experimental approaches to improve the accuracy of NEMURO.FISH saury growth model.

Shin-ichi Ito (Tohoku National Fisheries Research Institute, FRA)
Taizo Morioka (Hokkaido National Fisheries Research Institute, FRA)
Yasuhiro Ueno (Tohoku National Fisheries Research Institute, FRA)
Satoshi Suyama (Tohoku National Fisheries Research Institute, FRA)
Masayasu Nakagami (Tohoku National Fisheries Research Institute, FRA)

Today's contents

1. problems of NEMURO.FISH
2. raring experiments
3. model parameter estimation
4. future perspectives
NEMURO.FISH
NEMURO For Including Saury and Herring

Megrey et al. 2007
Bioenergetics Model for herring and saury

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

- **C**: consumption
- **R**: respiration (loses through metabolism)
- **S**: specific dynamic action (digesting food)
- **F**: egestion
- **E**: excretion
- **P**: egg production

change of weight
Several parameters were borrowed from herring since there were no information about the parameters of saury.

**Ito et al. (2004):** tuned the unknown parameters by fitting the growth to the observation and confirmed the model consumption rate showed realistic value (compare with other independent observation data). **Model was improved by:**
- Mukai et al. (2007), Ito et al. (2007), Megrey et al. (2007)

Several parameters are still unknown and we need more direct measurements of those parameters.

**Raring experiments are very limited.**
- Hotta (1958), Oozeki and Watanabe (2000) etc.
- We tried raring experiments.
**Raring experiment**

Use 12KL tank to rare the Pacific saury.
Caught eggs in the field and brought them to the tank.

April 29, 2005: 85 thousands larvae were hatched (about 7 mm BL)

<table>
<thead>
<tr>
<th>Prey</th>
<th>0 - 0 day</th>
<th>rotifer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 - 12 day</td>
<td>rotifer, Artemia</td>
</tr>
<tr>
<td></td>
<td>13-14 day</td>
<td>Artemia, copepoda</td>
</tr>
<tr>
<td></td>
<td>15-43 day</td>
<td>Artemia, copepoda, feedstuff</td>
</tr>
<tr>
<td></td>
<td>44-44 day</td>
<td>copepoda, feedstuff</td>
</tr>
<tr>
<td></td>
<td>45-52 day</td>
<td>feedstuff</td>
</tr>
<tr>
<td></td>
<td>53-349 day</td>
<td>feedstuff, mince (56-61 day &amp; after 141 day)</td>
</tr>
</tbody>
</table>
Age 240 days (Dec. 25)
25 cm KL
Start spawning
Experiments

**First year**

All saury died since they bumped to the wall.

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**Second year (covered the wall by vinyl sheet)**

1. Control (repletion) experiment
   Raring saury with repletion condition in the 20 degC water tank.
   - re-estimate consumption rate
   - estimate assimilation efficiency

2. Fasting experiment
   exclude prey consumption term

3. Ammonia estimate experiment
   estimate excretion directly
   (mainly done by Dr. Shiomoto)
   (not shown today)
Repletion experiment

Rapid growth than natural condition.
Pacific Saury Bioenergetics Model

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

\[F = a_F \cdot C \quad : \quad a_F = 0.16\]

\[E = a_E \cdot (C - F) \quad : \quad a_E = 0.10\]

\[SDA = S \cdot (C - F)\]

\[R = a_R \cdot W^{b_R} \cdot f_R(T) \cdot \text{activity} \cdot 5.258\]

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

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

\[f_R(T) = e^{(c_R \cdot T)}\]
Consumption of Pacific Saury

\[ C = C_r \cdot f_C(T) \]

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

\[ C_j = \frac{C_{MAX} \cdot PD_{ij} \cdot \nu_{ij}}{1 + \sum_{k=1}^{n} \frac{PD_{ik} \cdot \nu_{ik}}{K_{ik}}} \]

\[ C_{MAX} = a_C \cdot W^{b_C} \]

Hotta (1958) showed Cmax in laboratory was twice of field value. Ito et al. (2004) define Cmax curve to cross the twice value of the field observation (Kurita & Sugisaki 2004). But the data was limited between 60 -140 gWW fish.
Consumption rate

\[ y = 0.4286x^{0.2146} \]
\[ R^2 = 0.6334 \]

Prey Consumption

\[ y = 0.4286x^{0.7854} \]
\[ R^2 = 0.9586 \]

Wet weight of prey = 3.86 * dry weight of feedstuff + wet weight of mince
Calorie comparison of prey

Calorie equivalent for unit wet weight

Mince: 1269 cal/g
Feedstuff: 1178 cal/g
copepoda: 617 cal/g

Feedstuff: 4547.3 (cal/g) / 3.86 = 1178 cal/g
Convert the prey consumption to wet weight of copepoda

prey (g) = \((\text{mince} \times 1269 \text{ cal/g} + \text{feedstuff} \times 1178 \text{ cal/g}) / 617 \text{ cal/g}\)

\[ C_{MAX} = a_c \cdot W^{b_c} \]

- \(a_c = 0.8164\)
- \(b_c = -0.2121\)
Comparison between laboratory experiment and Ito et al. (2004)

- **Laboratory experiment** showed lower Cmax compared with Ito et al. (2004) especially in the larval stage.
- It becomes higher than the value in Ito et al. (2004) when it is converted to copepoda wet weight (especially in post larval stages).

Hotta (1958) showed Cmax in laboratory was twice of field value. Ito et al. (2004) define Cmax curve to cross the twice value of the field observation (Kurita & Sugisaki 2004). But the data was limited between 60 -140 gWW fish.
Pacific Saury Bioenergetics Model

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

The residual was calculated as the copepoda based value using the calorie ratio.
Residual

Allometry

\[(R + S + F + E + P) = 0.6227 \cdot W^{-0.1711}\]

Exponential function

\[(R + S + F + E + P) = 0.4797 \cdot e^{-0.0066W}\]
\[
\frac{(R + S + F + E + P)}{C} = 0.001 \cdot W + 0.8066
\]

Average 84% (SD 7.0%)
Experiments with different prey amount

Initial fish wet weight is 37.96g.
Feed different amount of prey and fish feed on all prey.

<table>
<thead>
<tr>
<th></th>
<th>prey</th>
<th>prey (cope)</th>
<th>rate</th>
<th>fish WW change</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.00g</td>
<td>0.0g</td>
<td>0.0%</td>
<td>-1.89g</td>
</tr>
<tr>
<td>B</td>
<td>7.80g</td>
<td>14.8g</td>
<td>3.9%</td>
<td>-1.33g</td>
</tr>
<tr>
<td>C</td>
<td>32.75g</td>
<td>62.0g</td>
<td>6.3%</td>
<td>+1.30g</td>
</tr>
<tr>
<td>D</td>
<td>42.77g</td>
<td>80.9g</td>
<td>21.3%</td>
<td>+4.81g</td>
</tr>
</tbody>
</table>
Experiments with different prey amount

In the case C=0, R=0.0192 gprey/gfish/day.
On the assumption R is constant with prey density, we estimated S+F+E.

<table>
<thead>
<tr>
<th>dw/w/dt 1/day</th>
<th>C (cope) gprey/gfish/day</th>
<th>R+S+F+E gprey/gfish/day</th>
<th>S+F+E</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-0.00498</td>
<td>0.0000</td>
<td>0.0192</td>
</tr>
<tr>
<td>B</td>
<td>-0.00350</td>
<td>0.0389</td>
<td>0.0524</td>
</tr>
<tr>
<td>C</td>
<td>0.00343</td>
<td>0.1632</td>
<td>0.1500</td>
</tr>
<tr>
<td>D</td>
<td>0.01267</td>
<td>0.2131</td>
<td>0.1641</td>
</tr>
</tbody>
</table>
Experiments with different prey amount

\[ (S + a_F + a_E - S \cdot a_F - a_E \cdot a_F) \]

Ito et al. (2004): 0.370, 0.391
Rare-full: 0.84 (min 0.72)
Rare-reduce: 0.73

much larger than
Ito et al. (2004)

<table>
<thead>
<tr>
<th></th>
<th>Ito et al. (2004)</th>
<th>Raring experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>juvenile</td>
<td>adult</td>
</tr>
<tr>
<td>S</td>
<td>0.150</td>
<td>0.175</td>
</tr>
<tr>
<td>aF</td>
<td>0.160</td>
<td>0.160</td>
</tr>
<tr>
<td>aE</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>total</td>
<td>0.370</td>
<td>0.391</td>
</tr>
</tbody>
</table>

ammonia experiment not shown today
Table 3. Summary of the parameter values used in the saury bioenergetics model.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_C$</td>
<td>Intercept for $C_{MAX}$ at $(te1+te3)/2$</td>
<td>0.8 → 0.8164</td>
</tr>
<tr>
<td>$b_C$</td>
<td>coefficient for $C_{MAX}$ versus weight</td>
<td>-0.340 → -0.2121</td>
</tr>
<tr>
<td>$te1$</td>
<td>Temperature for $xk1$ (in °C)</td>
<td>5</td>
</tr>
<tr>
<td>$te2$</td>
<td>Temperature for $xk2$ (in °C)</td>
<td>20*, 16#</td>
</tr>
<tr>
<td>$te3$</td>
<td>Temperature for $xk3$ (in °C)</td>
<td>26*, 20#</td>
</tr>
<tr>
<td>$te4$</td>
<td>Temperature for $xk4$ (in °C)</td>
<td>30</td>
</tr>
<tr>
<td>$xk1$</td>
<td>Proportion of $C_{MAX}$ at $te1$</td>
<td>0.10</td>
</tr>
<tr>
<td>$xk2$</td>
<td>Proportion of $C_{MAX}$ at $te2$</td>
<td>0.98</td>
</tr>
<tr>
<td>$xk3$</td>
<td>Proportion of $C_{MAX}$ at $te3$</td>
<td>0.98</td>
</tr>
<tr>
<td>$xk4$</td>
<td>Proportion of $C_{MAX}$ at $te4$</td>
<td>0.5</td>
</tr>
</tbody>
</table>

red: revised by raring experiment
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<th>Value</th>
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</thead>
<tbody>
<tr>
<td>$a_R$</td>
<td>Intercept for $R$</td>
<td>0.0033 → 0.0054</td>
</tr>
<tr>
<td>$b_R$</td>
<td>Coefficient for $R$ versus weight</td>
<td>-0.227 → -0.271</td>
</tr>
<tr>
<td>$c_R$</td>
<td>Coefficient for $R$ versus temperature</td>
<td>0.020 → keep</td>
</tr>
<tr>
<td>$d_R$</td>
<td>Coefficient for $R$ versus swimming speed</td>
<td>0.026 → keep</td>
</tr>
<tr>
<td>$S$</td>
<td>Coefficient for Specific Dynamic Action</td>
<td>0.150a, 0.175b → keep</td>
</tr>
</tbody>
</table>

Swimming Speed, $U$

| $a_A$  | Intercept $U$ (< 12 °C) (in cm/s) | 2.0 |
| $a_A$  | Intercept $U$ (≥ 12 °C) (in cm/s) | 12.3 |
| $b_A$  | Coefficient $U$ versus weight | 0.33 |
| $c_A$  | Coefficient $U$ versus temperature (< 12 °C) | 0.149 |
| $c_A$  | Coefficient $U$ versus temperature (≥ 12°C) | 0.0 |

a - values for stage 1 saury

b - values for stage 2 and higher saury

green: value referred to herring
Table 3. Summary of the parameter values used in the saury bioenergetics model.

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<tr>
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<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_F$</td>
<td>Proportion of consumed food to egested</td>
<td>0.16→0.350, 0.309</td>
</tr>
<tr>
<td>$a_E$</td>
<td>Proportion of consumed food to excreted</td>
<td>0.10→0.430</td>
</tr>
<tr>
<td>$a_P$</td>
<td>Proportion of consumed food to egg production</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Egestion and Excretion, F and E
Future Perspectives

Further model improvements are necessary to reduce uncertainty.
- experiments with other temperatures
- swimming speed (video analysis)
- egestion estimation

Requirements for ecosystem based management model
- proper model for target species (resolve life history)
- reflect direct environmental factors (temp, current)
- interaction between prey production, hence ocean structure
- species interaction (competition, predators, etc.)
- hence, migration (at least 2 dimension)

Please see NEMURO mafia 15 presentations.
S1(Cisco, Preikshot), S2(Fujii), S3(Kishi, Talyor, Okunishi, Shido, Ito), S5(Megrey), S9(Hermann, Colbert), BIO(Ito), CCCC(Wei), W3(Megrey), W6(Hashioka)