Modeling the dynamics of male / female function in starving hermaphrodites

DEBtox: general philosophy and concept
DEBtox: general philosophy and concept

- DEB: Dynamic Energy Budget
  - Uses mass and energy balance to quantify investment in different processes
  - Toxic effects: disturbance of the balance

```
feeding
```

```
maintenance
```

```
growth
```

```
reproduction
```
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EC50
DEBtox: general philosophy and concept

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![Diagram showing feeding, reproduction, maintenance, and growth processes](image-url)

- **feeding**
- **reproduction**
- **maintenance**
- **growth**

**EC50**
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The perfect ecotoxicological experiment

- For DEB application:
  Should enable us to determine the metabolic mode of action (mMoA)

- Poster Nr. 24
The pond snail under stress

The pond snail *Lymnaea stagnalis*
The pond snail under stress

The pond snail *Lymnaea stagnalis*

- Large aquatic freshwater snail
- Soon-to-be standard test organism (OECD guidelines 2015)
- **Simultaneous hermaphrodite**
  -> sexual conflict
Simultaneous hermaphrodites

- Maintain male + female function at the same time
- Cross fertilization preferred, but selfing possible
- Trade-off male vs female function: sexual conflict
- Mating frequency determines reproduction rate

Do we need to be concerned about the simultaneous hermaphroditism in the pond snail *L. stagnalis* in ecotoxicological experiments?
Experimental setup

- “The starving-mothers experiment”: stressor is resource limitation
Experimental setup

“The starving-mothers experiment”: stressor is resource limitation

Initial conditions: sexually mature snails from the culture (2.5 cm), fed *ad libitum* for 2 weeks

4 feeding regimes

2 mating regimes:

- Singles, only mated in the culture
- Pairs, could mate continuously
**Experimental setup**

<table>
<thead>
<tr>
<th>days of experiment</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>...</th>
</tr>
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<tbody>
<tr>
<td>ad libitum</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>limited</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>interval feeding</td>
<td>c</td>
<td>c</td>
<td>c</td>
<td>c</td>
<td>c</td>
<td></td>
</tr>
<tr>
<td>starvation</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>X</td>
</tr>
</tbody>
</table>

- **ad libitum**: Food available at all times.
- **limited**: Food available in limited amounts.
- **interval feeding**: Food available at specific intervals.
- **starvation**: No food available.
The results
The results

- No significant effect of mating, only in the highest feeding regime after a couple of weeks

- NEC for substances in sperm?

- So we don't need to consider male/female function? → WRONG

![Graph showing cumulative reproduction over time for paired and single snails.](graph.png)
The model
The model

- feeding
- maintenance
- growth
- reproduction
The model

Foodfeeding → assimilation → Reserve

Foodfeeding → Faeces

Feeding → maintenance → growth → reproduction
The model

FOOD -> feeding -> RESERVE
<table>
<thead>
<tr>
<th>assimilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>mobilization</td>
</tr>
<tr>
<td>growth</td>
</tr>
<tr>
<td>somatic maintenance</td>
</tr>
</tbody>
</table>

FAECES

feeding

maintenance

growth

reproduction
The model

FOOD → feeding → assimilation → RESERVE → mobilization → growth → somatic maintenance → maturity → maintenance → maturation / reproduction → STRUCTURE

feeding

maintenance

growth

reproduction
The model

FOOD → feeding → assimilation → RESERVE → mobilization → maturity → maturation / reproduction → STRUCTURE

FAECES

Standard: 95% is translated into eggs, 5% overhead

feeding

maintenance

growth

reproduction
The model

FOOD → feeding → assimilation → RESERVE → mobilization → FAECES → feeding

RESERVE → growth → somatic maintenance → maturation / reproduction

FAECES → maturation / reproduction

OVERHEAD → SPERM → EGGs
Simultaneous hermaphrodites

- *Lymnaea stagnalis*: 50% less eggs when mating continuously

De Visser et al (1994)
The model

- **OVERHEAD**
  - **SPERM**
  - **EGGS**

- **5 %**
- **95%**
- **50 %**
- **50%**
The model

<table>
<thead>
<tr>
<th>OVERHEAD</th>
<th>SPERM</th>
<th>EGGS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5%</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>50%</td>
</tr>
</tbody>
</table>

measured endpoint
Food limitation and sexual conflict combined?
The model: parameterization
The model: parameterization

- Parameterization: 3 constant food levels
  - Respiration, egg development
  - V1 morphic acceleration
  - 50% into each sexual function
Modeling the results
- We use the mean values: no effect of mating

- Assumption: all mainly invest in the female function (95%)
  → negligible costs for mating with one partner

- Standard DEB model cannot capture the pattern under starvation
The starvation response: hungry males

Assumptions:
The starvation response: hungry males

Assumptions:

- Starvation response starts following standard DEB rules: when the snails start using body tissue to pay maintenance ($e < l$)

- Investment into the female function is reduced until they are adapted to the new food level ($e \approx f$)

→ they are “more male” during the adaptation to the new situation
The model fits
Starvation response is initiated:
- first in the full starvation
The model fits

Starvation response is initiated:
- first in the full Starvation
- next in the lowest feeding regime
The model fits

Starvation response is initiated:
- first in the full Starvation
- next in the lowest feeding regime
- then in the higher feeding regime
Starvation response is initiated:
- first in the full Starvation
- next in the lowest feeding regime
- then in the higher feeding regime

The model fits
Starvation response is stopped:
- first in the higher feeding regime
Starvation response is stopped:
- first in the higher feeding regime
- then in the lowest feeding regime
Starvation response is stopped:
- first in the higher feeding regime
- then in the lowest feeding regime
Simultaneous hermaphrodites are known to (relatively) decrease the female investment under resource limitation.

But why should they go back to the original (relative) investment?
Implications for ecotoxicological testing

- Adaptations lead to stronger reduction in reproduction → Conditions prior to experiment have major influence

- Food limitation is more influential than mating regime: good news

- BUT: the reproductive system is very flexible → careful experimental planning crucial (no sudden changes shortly before testing)

- Analysis of test results with an energy budget approach can help understand test results better
Questions?

ezimmer@sckcen.be

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Mini-Symposium “New developments in quantitative energetics: individuals, effects of toxicants and population dynamics” 18th of June, VU Amsterdam