Supplements for: Simple energy-budget model for yolk-feeding stages of Atlantic cod (*Gadus morhua*)

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Contents

1 Response on starvation

When the allocated assimilation flux κJ_A is insufficient to cover the maintenance costs J_M, the animal has a problem, and needs to deviate from the model provided in the main text. Jager *et al.* [2] proposed a simple model to deal with this problem in two stages.

In the first stage (mild starvation), the allocated assimilation flux to the soma is insufficient to pay maintenance costs, but the total assimilation flux is sufficient, and the animal will divert energy from the maturation flux J_H. In the second stage (strong starvation), the total assimilation flux is insufficient to pay maintenance costs, and the animal will shrink (use structural tissue to pay the maintenance cost). This can be summarised as follows:

$$\text{if } \kappa J_A < J_M \text{ and } J_A \geq J_M : J_V = 0 \text{ and } J_H = J_A - J_M \tag{1}$$

$$\text{if } J_A < J_M : J_V = (J_A - J_M)/y_{AV} \text{ and } J_H = 0 \tag{2}$$

In the model for yolk-feeding stages, and in the complete absence of external food, we can skip the mild starvation stage: f will switch from 1 (as long as $W_B > 0$) to zero (when $W_B = 0$) instantly, and simplify the shrinking equation (as $J_A = 0$). However, if a smoother transition from $f = 1$ to $f = 0$ is implemented, the full two-stage starvation model will be needed.

To explore a smoother transition, it is possible to extend the model. In the standard model, the assimilation rate is determined by structural body size only:

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$$J_A = f J^a_{Am} L^2 \tag{3}$$

As suggested by Beer & Anderson [1], the rate of yolk absorption may be governed by the surface area of the yolk sac, when yolk is close to exhaustion. We can extend the assimilation flux by a squared volumetric length measure for the yolk sac (L_B) as well:

$$J_A = f J^a_{Am} \min(L^2, aL_B^2) \quad \text{with } L_B = \left(\frac{W_B}{d_B}\right)^{1/3} \tag{4}$$

The factor a would be used as a surface-area correction. As both L and L_B are volumetric lengths (cubic root of a volume) their squared values are not a true surface area; they will be *proportional* to the true area, as long their shape does not change, but the proportionality may differ between structure and yolk (and hence a may deviate from 1).

2 Fits for temperature/light data

To investigate the effects of light and temperature, we use data from Solberg & Tilseth [3] at three temperatures and two light regimes (continuous light or darkness). Fits are shown in Figure 1 and 2. Only the specific assimilation and maintenance rate constants are fitted; other parameters were fixed to the values of Table 1 in the main text. The measurements start closely after hatching, and $t = 0$ is set here at the start of the measurement series for each treatment. In most fits, the last part of yolk absorption is slower than predicted by the model (with the exception of dark, 7°C).

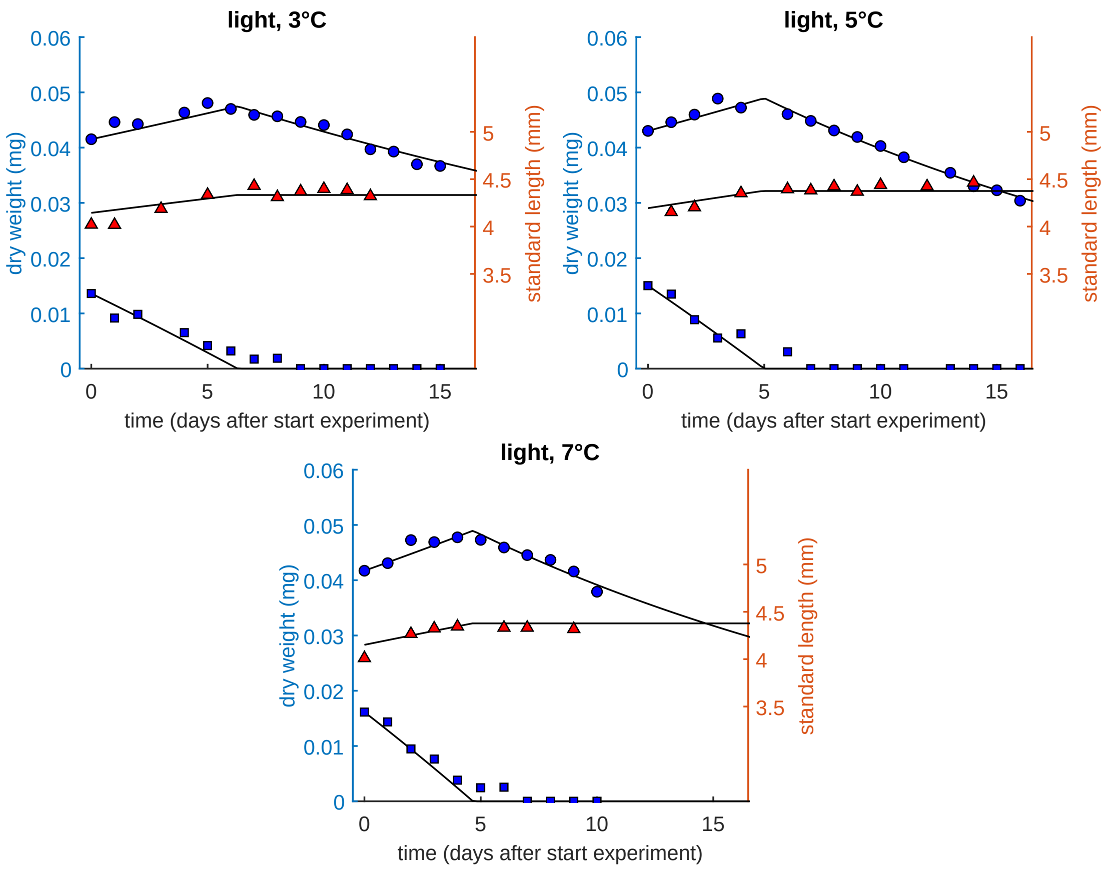

Figure 1: Fits of the DEBkiss model to data for yolk weight (squares), larval weight (circles), and standard length (triangles) post hatching. Animals kept under constant light.

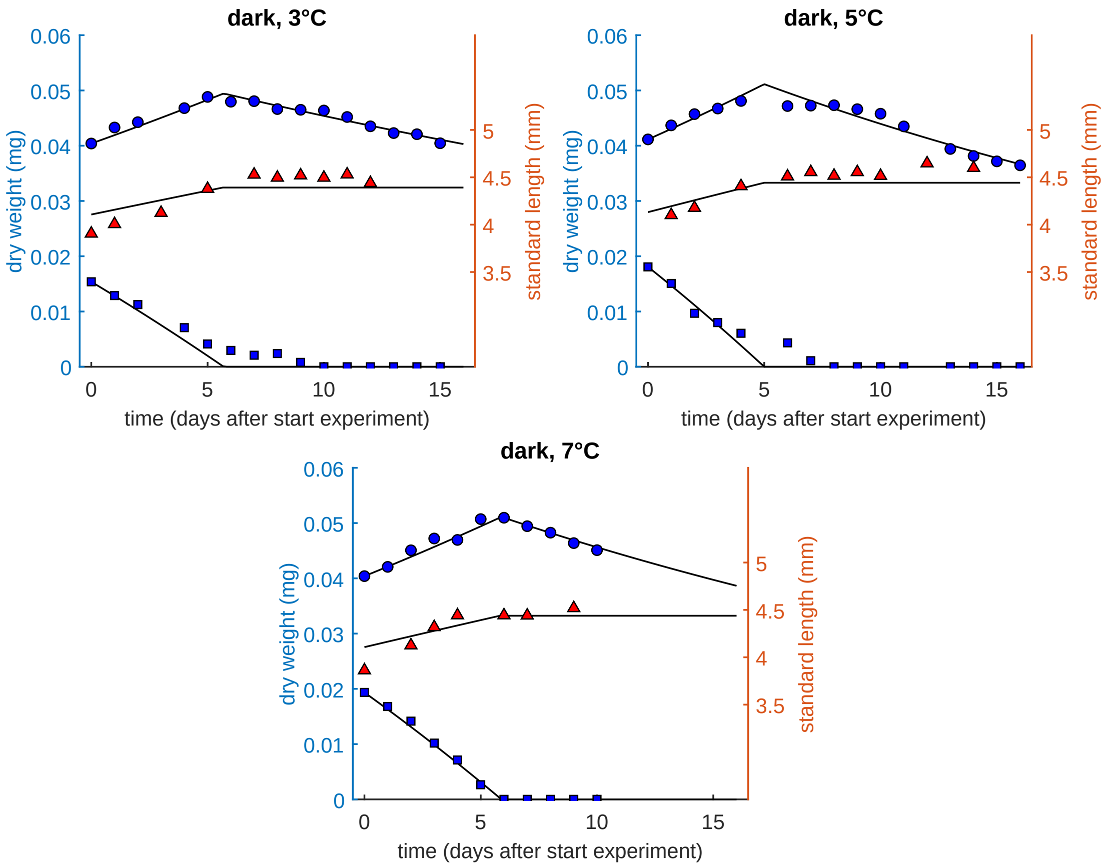

Figure 2: Fits of the DEBkiss model to data for yolk weight (squares), larval weight (circles), and standard length (triangles) post hatching. Animals kept under constant darkness.

References

[1] W. N. Beer and J. J. Anderson. Modelling the growth of salmonid embryos. *Journal of Theoretical Biology*, 189(3):297–306, 1997.

[2] T. Jager, B. T. Martin, and E. I. Zimmer. DEBkiss or the quest for the simplest generic model of animal life history. *Journal of Theoretical Biology*, 328:9–18, 2013.

[3] T. Solberg and S. Tilseth. Growth, energy consumption and prey density requirements in first feeding larvae of cod (*Gadus morhua* L.). In E. Dahl, D. S. Danielsen, E. Moksness, and P. Solemdal, editors, *The propagation of cod Gadus morhua L. Flødevigen rapportser 1*, pages 145–166. 1984.