Simple energy-budget model for yolk-feeding life stages
Case study for Atlantic cod

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Introduction

Atlantic cod (*Gadus morhua*) is commercially important, and therefore, understanding the influence of stressors on its early-life stages is of considerable relevance. However, understanding the action of stressors requires a model for the unstressed situation. Here, we apply a simple and generic energy-budget framework (DEBkiss) to data for the yolk-feeding stages on yolk volume, body size, and oxygen use over time.

This study was already published (Jager *et al*, 2018). In ongoing work, the model will be used to explain effects of marine mine tailings on early-life stages of fish (see https://ditail.no/en/).

Model calibration

The DEBkiss model was calibrated using data from the literature (Finn *et al*, 1995). The animals were not fed, and need to shrink when yolk runs out. The model is able to explain all four endpoints simultaneously, over time, with one set of parameters (Fig. 2).

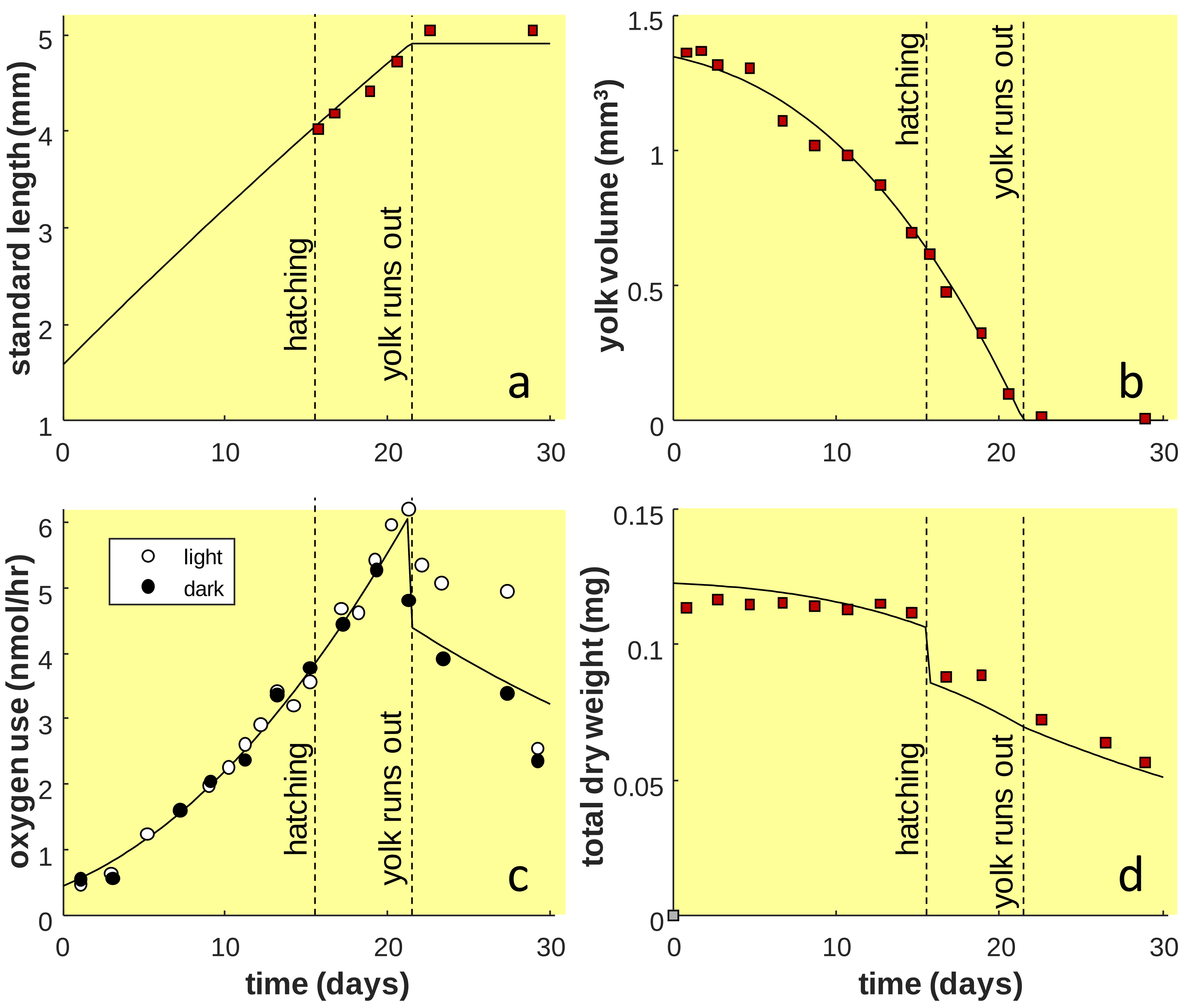

Fig. 2. Model fit of the DEBkiss model to data for early life stages (all endpoints fitted simultaneously).

Relation to molecular work

Substantial research effort is currently focussing at the molecular level. Molecular-level approaches can be combined with energy-budget models to allow for a causal, dynamic, link between stressor exposure and whole-organism life-history traits (as represented by AoPs). The reasons for this are twofold:

1. AoPs require toxicokinetics (TK): how internal concentrations develop over time. TK is influenced by changes in structure and yolk over time.
2. Life-history traits are themselves not independent, but connected through the energy budget, and feedbacks at this level cannot be explained from the molecular level up.

Linking DEB-based models and AoPs is currently sparking considerable interest (e.g., Murphy *et al* 2018), although more work is urgently needed.

Model structure

The DEBkiss model for yolk-feeding stages consists of two state variables: yolk and structural biomass (Fig. 1). When the yolk supplement runs out, the individual must fuel its life history from feeding. When no food is present, the animals need to shrink to pay maintenance costs from structure.

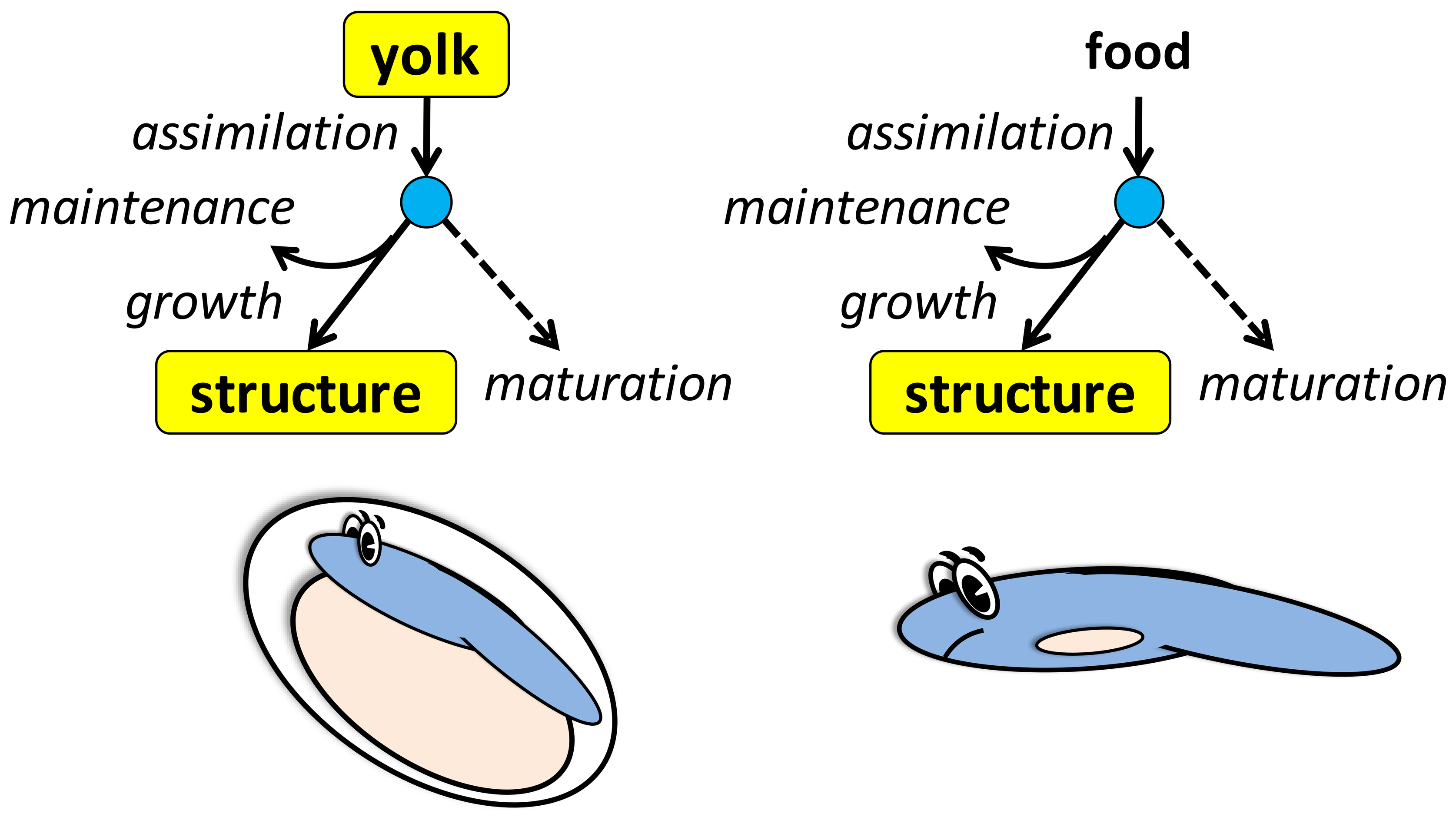

Fig. 1. Schematic representation of the DEBkiss model for early life stages: yolk-feeding embryo (left) and free-feeding larva (right).

Main model assumptions:

1. Yolk assimilation is proportional to structural surface area.
2. Maintenance costs are proportional to the structural mass.
3. Assimilation is split with a constant fraction κ to the soma (structure plus maintenance).
4. Body length is proportional to structural mass to the power 1/3, but animals cannot shrink in length.
5. Respiration is the sum of maintenance, maturation and overheads of the growth process.
6. In absence of food, animals burn structure to pay maintenance.

Simulations for toxicant effects

Toxicant and other stresses will affect the energy-budget processes (Fig. 1), and thereby development of the early-life stages. Figure 3 shows that the stressor's mechanism of action can, in principle, be inferred from observations on yolk, body size and oxygen use.

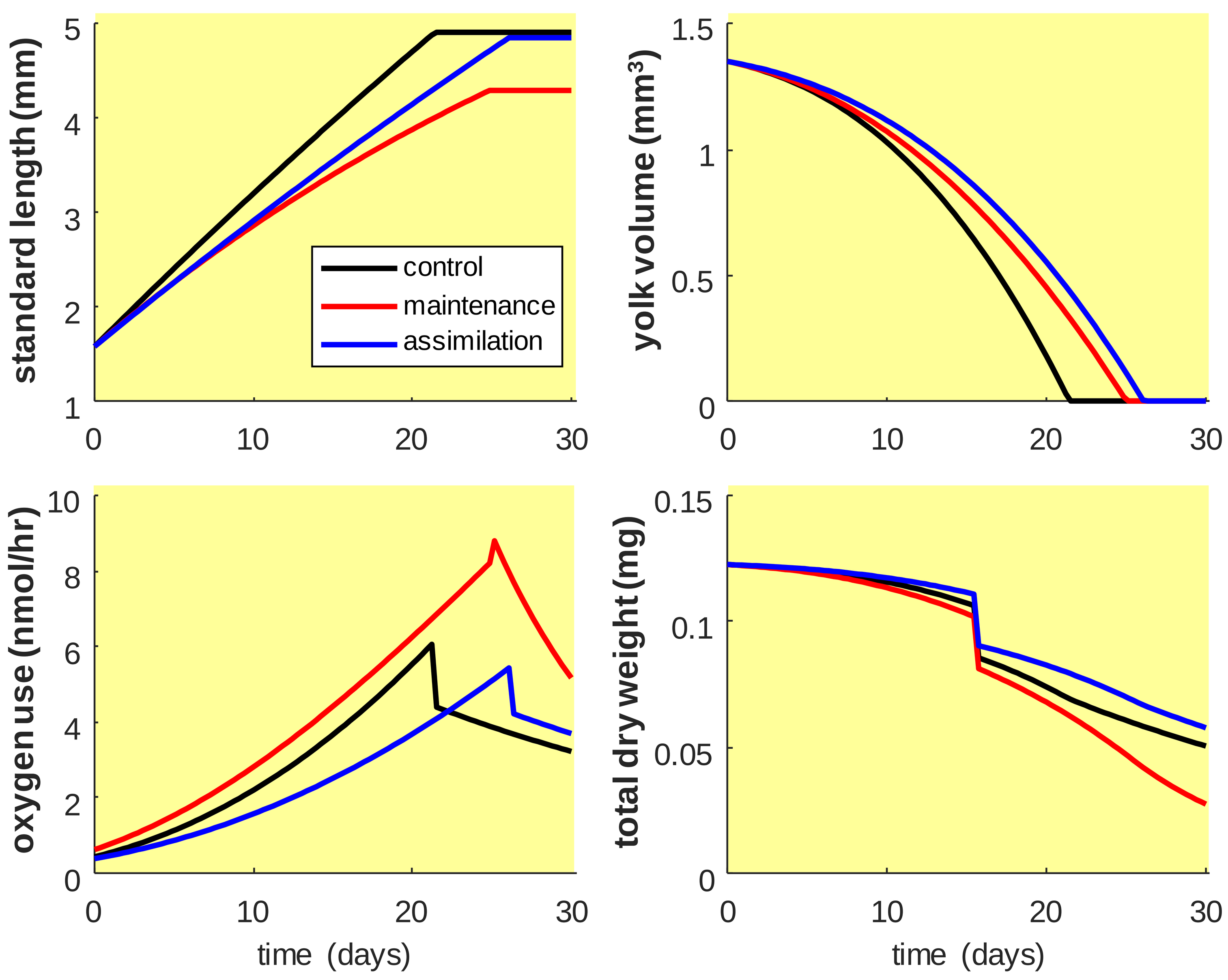

Fig. 3. Model simulations for a constant increase in maintenance costs or a decrease in assimilation rate.

References

Finn *et al* (1995). Physiological energetics of developing embryos and yolk-sac larvae of Atlantic cod (*Gadus morhua*).I. Respiration and nitrogen metabolism. Mar Biol 124:355.
Jager *et al* (2018). Simple energy-budget model for yolk-feeding stages of Atlantic cod (*Gadus morhua*). Ecol Mod 385:213.
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Acknowledgements

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