Reserve dynamics of oysters during starvation

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Introduction

Pacific oyster, *Crassostrea gigas*, is a commercially important species worldwide. Management of aquaculture industries needs good understanding of the growth dynamics. Therefore, energetic model is a useful tool in understanding energy acquisition and expenditure within the organism taking into account of varying environments.

The present study is to understand how reserves are used at conditions of non-food supply in oysters. For the practical application, the structure of the model is aimed to be kept as simple as possible (as few assumptions as possible) in order to obtain model parameters from experiments.

Model structure

The dynamics of reserves, dE/dt, within an organism is the difference between assimilation, P_A, and expenditure, P_C, assuming that the changes of energy in blood $dE_{bl}/dt \cong 0$, following Chapter 3 (Kooijman 2000), so

$$dE/dt = P_A - P_C \quad (1)$$

At starvation, the assimilation $P_A = 0$. The dynamics of reserves at the particular condition can be written as solely loss of energy as $dE/dt = -P_C$.

Following *k*-rule, the growth plus maintenance is described as

$$k \cdot P_C = [E_G] \cdot dV/dt + [P_M] \cdot V \quad (2)$$

where *k* is a fraction of catabolic power energy spent on maintenance plus growth, $[E_G]$ stands for volume-specific of growth, $[P_M]$ is volume-specific maintenance rate and V is structural body volume. At starvation, the energy invested in growth would be negligible and hence I assume $dV/dt \cong 0$.

Development (P_D) and reproduction (P_R) costs are modelled as

$$(1-k) \cdot Pc = P_D + P_R \quad (3)$$

Energy requirement for development and reproduction depends on the level of reserves in excess of a minimum level that increases with the size. Below the minimum level, ie. core level of reserves: $S_C=[E_D] \cdot V$, the development stops. Therefore, the equation 3 can be written as

$$(1-k) \cdot Pc = [P_D] \cdot (E-[E_D] \cdot V) + [P_R] \cdot (E-[E_D] \cdot V) = ([P_D] + [P_R]) \cdot (E-[E_D] \cdot V) \quad (4)$$

where $[P_D]$ is volume-specific cost for development, $[P_R]$ is volume-specific cost for reproduction and $[E_D]$ is volume-specific coefficient for development and reproduction.

Experimental data

1. Dry weight and reserves

In obtaining model parameters and testing applicability of the model, starvation experiments have been conducted in the laboratory at constant temperature (18 ± 2^oC). The changes of reserves and metabolisms have been monitored at starvation experiments at constant temperature. Based on DEB theory in Chapter 2, the reserve materials can be distinguished from materials of the structural mass by a change in relative abundance if resource levels changes. Therefore, structural materials can be measured at starvation, which is the weight when all reserves are depleted. Since death may not occur immediately when all reserves were depleted due to the utilisation of structural tissue (Kooijman, 1993), the point at which reserves were used

up was decided using the following criteria: 1) dry tissue weight remained constant (at the level of detection); 2) oxygen consumption rate no longer decreased but remained constant (at the detection limitation). The core weight was measured as DTW at the end of starvation. The reserves were estimated by subtracting core weight from total dry flesh weight during the course of starvation.

The experiment lasted for 170 days and the dry flesh weight became relatively constant from day 113. At which time, I therefore assume that reserves were almost depleted and the DFW was approximately structural tissue, ie core weight (Fig. 1).

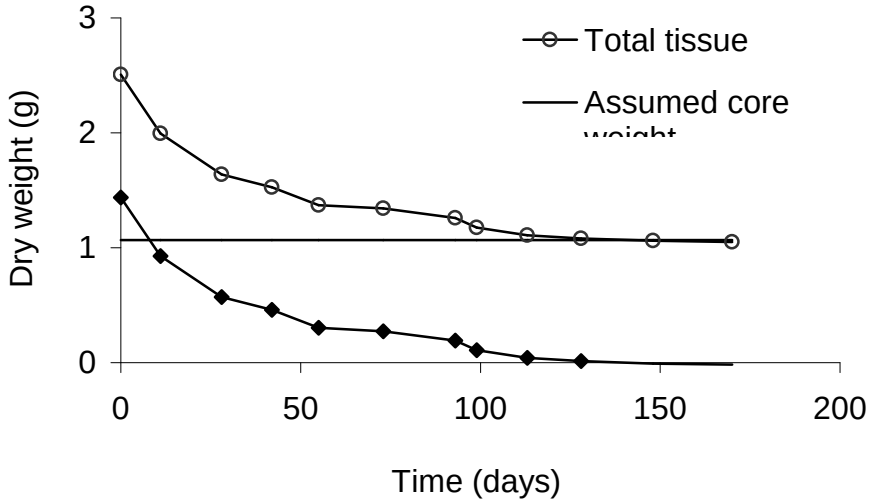

Fig. 1. Changes of total dry flesh weight and storage during starvation, relative to the core weight.

2. Respiration

Respiration rates have been measured in terms of oxygen consumption rates at beginning of starvation, which was regarded as total metabolic requirements including maintenance and growth costs, development and reproductive costs. Maintenance cost can be measured as oxygen consumption when growth, development and reproduction stop according to DEB theory, ie. oxygen consumption (VO_2: ml O_2 h^{-1}) at reserves being depleted. Measurements of oxygen consumption has been described in detail

elsewhere (Ren et al. 2000). Oxygen consumption rate at beginning of starvation was measured as:

$VO_2 = aV$ $(R^2=0.90, n=149)$ (5)

where the volume-specific oxygen consumption coefficient a = 0.200 (ml O_2 $d^{-1}cm^{-3}$) and V is structural volume (ml or mm^3)

Thereafter it was monitored weekly from day 70 till the end of the experiment (day 170). The oxygen consumption rate became relatively constant (at detecting level) from day 90 (data not shown), suggesting that the growth, development and reproduction stopped from day 90. The oxygen consumption rate was considered as maintenance cost, which can be expressed as:

$VO_2 = \delta V$ $(R^2=0.88, n=138)$ (6)

where the volume-specific total cost coefficient δ = 0.136 (ml O_2 $d^{-1}cm^{-3}$).

3. Morphormetrics of oysters

The relationships between core weight (W_C: g), volume (V: cm^3) and length (L:cm) in experiments were fitted by the following allometric functions:

$W_C=1.85\times10^{-2} \cdot V$ $(R^2=0.83, n=89)$ (7)
$W_C=5.52\times10^{-3} \cdot L^{2.23}$ $(R^2=0.88, n=108)$ (8)

Model Inputs

The forcing data are reserves from Fig. 1 and volume (at a constant value of 56 ml for my purpose). Reserves were calculated in terms of dry flesh weight (DFW). For the present purpose, it was converted into energy using conversion factor of 20.23 J mg^{-1} DFW. Metabolic rates were measured in terms of oxygen consumption rates. For the purpose of model simulations, they were also converted into energy using conversion factor of 20.36 J ml O_2^{-1}. I could not obtain volume-specific coefficient for development and reproduction from my experiment. Using published information:

$S_C=0.1W_C$ mgC (Ren & Ross, in press) and my experiment (Eqs. 7 & 8), it is estimated as $[E_D]=32$ J ml^{-1}.

No spawning was observed at any time of the experiment, I assume that $[P_R]=0$. Still I do not have sufficient data to estimate the volume-specific cost for development estimate $[P_D]$. It was estimated by 'free-fit' – i.e. the values of the parameters used in model simulations were adjusted until an acceptable fit was achieved between simulations and observed dataset. Hence $[P_D]=0.0002$ from the best fit.

Results

Dynamics of observed reserves matched reasonably well with simulations (Fig. 2). It seems that most of energy reserves went to development whilst maintenance required only very small proportion (Fig. 3). Development stopped at day approx. 100.

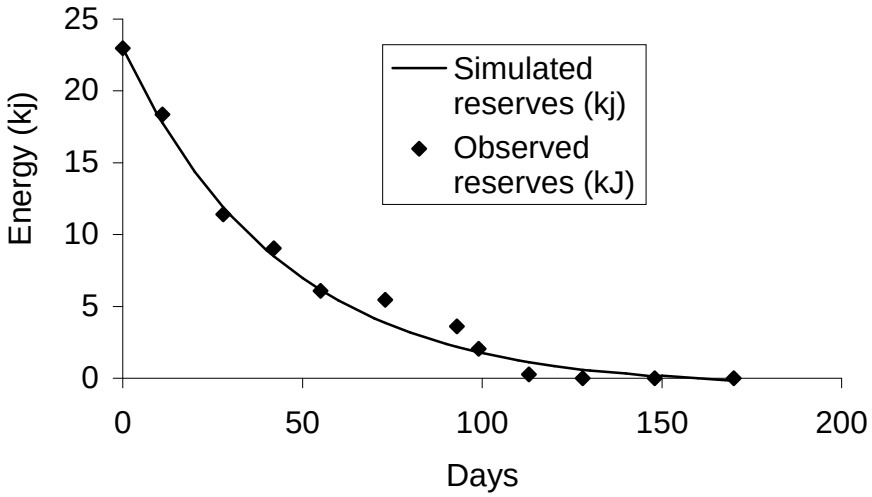

Fig. 2. Simulated and observed reserves

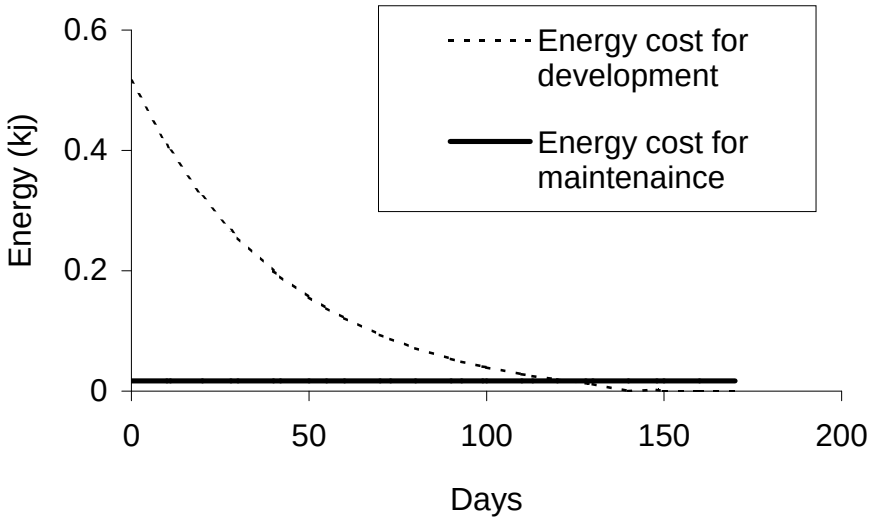

Fig. 3. Simulated costs for development and maintenance

Discussion

The model did not include excretion, because I did not measure excretion rate. However, it contributes to a very little portion and is negligible (Deslous-Paoli et. al. 1990). It seems reasonable that the metabolic rate measured at beginning of starvation is considered as total costs for feeding, growth, development and maintenance.

Although the model simulations matched reasonably well with observed data, I am still not confident about the development cost that is considerably high comparing with maintenance cost (Fig. 3). Furthermore, the parameter of volume-specific coefficient for development, $[E_D]$, seems underestimated, because at $[E_D]$=32 J ml^{-1} (ie. when total energy reserves is less than $[E_D] \cdot V$=1800 J for my experimental animals of 10 cm), development did not stop until day 100 of starvation. What I am not convinced is the ability of oyster to continue to develop game at such an extreme starvation. Furthermore, the 'free-fitting' parameter, $[P_D]$, volume-specific coefficient for development might not well represent the true value. However, I have tried to vary its value, the estimated value ($[P_D]$=0.0002) is from the best fit between observations and simulations.

References

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Acknowledgements

I would like to express my sincerely thanks to Prof. Bas Kooijman and one other reviewer (ID=22) for their constructive comments.

Please note that this is the revised version of my assay. I have taken some of reviewers' comments in this new version. However, due to time limitation, I could not include all aspects of the comments for the time being. I am seriously considering all the comments and improving the assay towards a journal paper by including other aspects of oyster energetics into the analysis such as feeding, growth, reproduction and respiration under non-stress conditions.