Growth potential of shrimp exposed to different temperatures and salinities evaluated by a dynamic energy budget model

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Abstract

The Pacific white shrimp, *Litopenaeus vannamei*, is a worldwide commercial crustacean species. The strong osmoregulation and ion regulation capacity enables its tolerance of wide salinity range, which allows farming in marine and freshwater. The growth of Pacific white shrimp under different conditions (temperature and salinity), is still unknown. We used dynamic energy budget (DEB) model to investigate the potential influence of temperature and salinity on growth of the shrimp. In this paper, we first developed an individual-based mathematical model (Dynamic Energy budget (DEB) model) on top of the standard food and temperature variables and calibrated with field and experimental data. To measure the influence of salinity level on shrimp growth, we used salinity as the third environmental variable in our DEB model. Two potential mechanisms were tested to explain changes in shrimp's size and weight when salinity was out of ideal range: (1) negative effect on assimilation and (2) additional somatic maintenance cost. Based on laboratory experiments, the key parameters of maintenance ($[\dot{p}_M]$) and volume-specific cost for growth ($[E_G]$) were obtained. The model was then applied to simulate shrimp growth in Binzhou, Shandong Province in high salinity pond and in Guangxi Province in low salinity pond. Simulations indicated that shrimp growth in Binzhou was both temperature-limited and salinity-limited. While in Guangxi, shrimp growth was mainly salinity-limited. The observed negative influence of salinity on shrimp growth could be explained by decreases in assimilation and increases in somatic maintenance cost. This DEB model can be used to predict the influence of temperature and salinity changes on shrimp farming (e.g. in climate change studies). The model can also be a key sub-model of shrimp-based Integrated Multi-Trophic Aquaculture in the future.

Keywords: Pacific white shrimp (*Litopenaeus vannamei*), DEB model, parameterisation, salinity, growth

We used Kooijman's dynamic energy budget method to model lifetime growth of Pacific white shrimp (juvenile and puberty periods) via body length and wet weight growth. We derived following results:

- Based on our DEB model, we predicted length growth and wet weight growth of Pacific white shrimp in Binzhou (graph 1). The primary parameters (table 2) in the model are derived from formulas in Kooijman's book, *Dynamic Energy Budget (DEB) for metabolic organisation* and our experiment results. The parameters plugged into Stella DEB to produce result are illustrated in red color. DEB model simulation is done on Stella. Our models were adjusted based on on-site data from Binzhou, China, and reference data of Chunhua Zhu (2002) and Xingqiang Wang.
- When water salinity level was low (Guangzhou), we compared DEB models with adjusted and unadjusted salinity parameter. DEB model produced more accurate prediction of length growth when salinity is included in the model (graph 2 and 3). However, prediction of the growth of wet weight is inconsistent with added salinity parameter.

Further research is needed in terms of salinity influence in wet weight growth of Pacific white shrimp. In addition, *NicheMapR – an R package for biophysical modelling: the ectotherm and Dynamic Energy Budget models* by Kearney, M. R. and Porter, W. P. (2019) proposed an alternative DEB model with different parameters used. We are currently working on this version of DEB model.

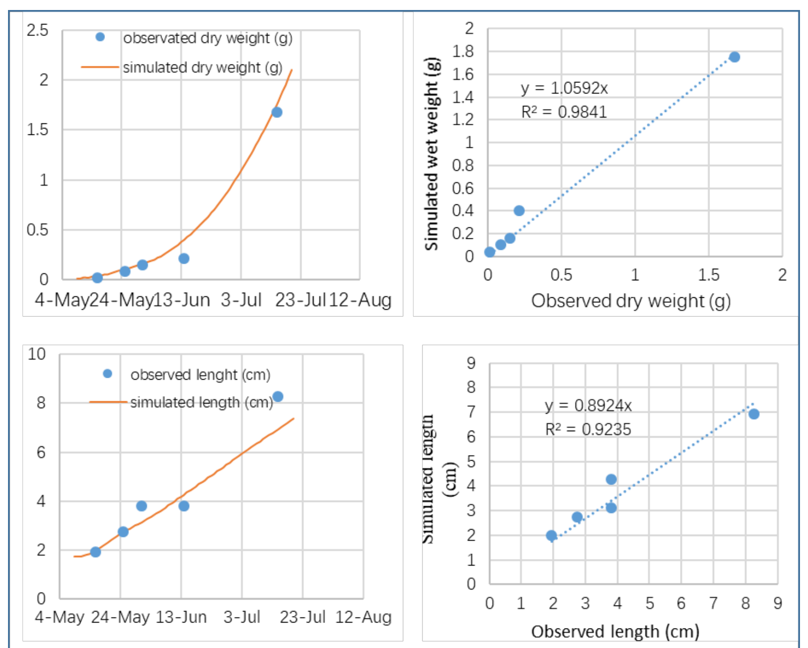

Fig 1: DEB on length growth of Pacific white shrimp in Binzhou, China

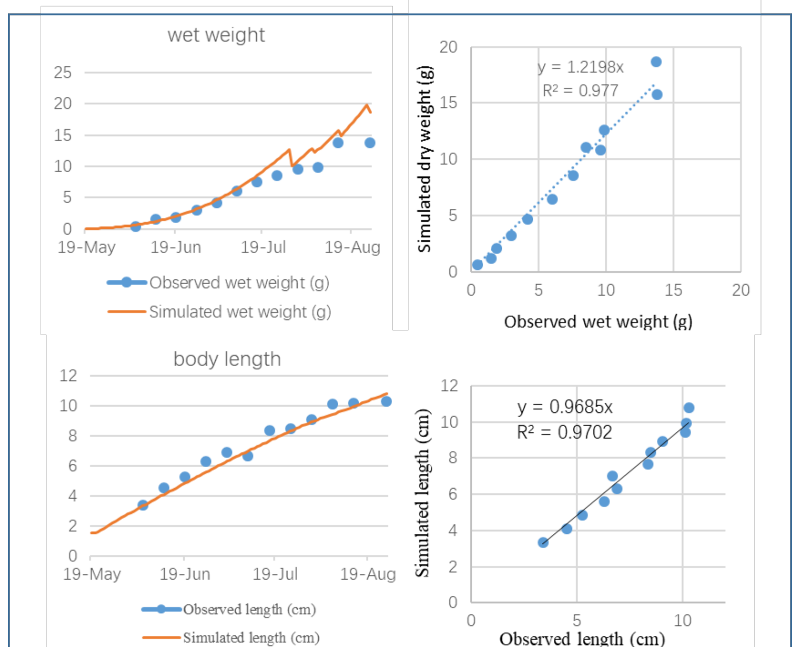

Fig 2: DEB model on length growth of Pacific white shrimp in Guangzhou, China. *(Adjusted for low salinity)*

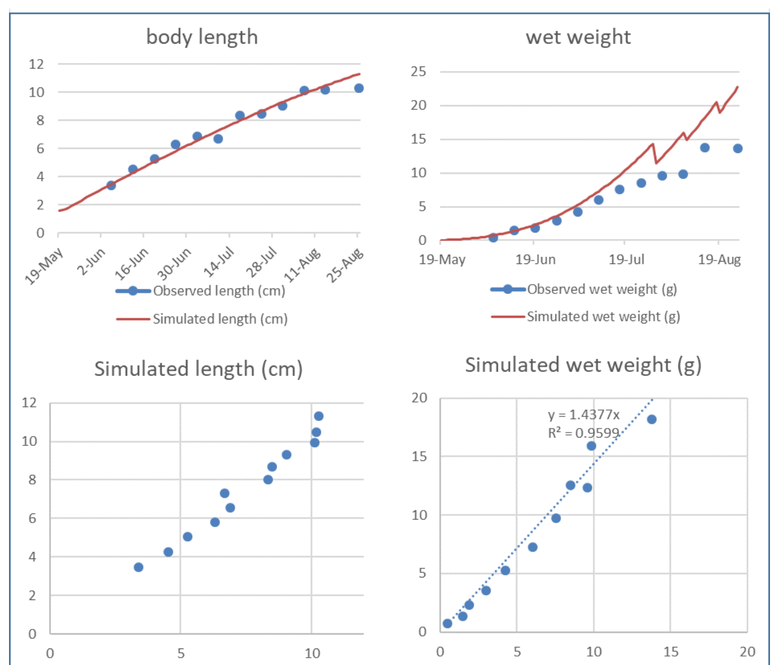

Fig 3: DEB model on length growth of Pacific white shrimp in Guangzhou, China. *(Unadjusted for low salinity)*

Table 1. DEB parameter values of shrimp *Litopenaeus vannamei*, corrected for the reference temperature of 28°C.

Symbol	Value	Dimension	Definition
$\{\dot{p}_{AX}\}$	850	J cm^{-2} d^{-1}	Maximum surface area-specific ingestion rate
$\{\dot{p}_{Am}\}$	637.5	J cm^{-2} d^{-1}	Maximum surface area-specific assimilation rate
κ_X	0.85	–	Digestion efficiency of food to reserve
κ_P	0.1	–	Faecation efficiency of food to faeces
$\dot{\upsilon}$	0.022	cm d^{-1}	Energy conductance
κ	0.7	–	Allocation fraction to soma
κ_R	0.95	–	Fraction of reproductive energy fixed in eggs
$[\dot{p}_M]$	114	J cm^{-3} d^{-1}	Volume-specific maintenance rate
$[E_m]$	2860	J cm^{-3}	Maximum storage density for female
$[E_G]$	2910	J cm^{-3}	Volume-specific costs for structure
δ_M	0.22/0.205	–	Shape coefficient*
*the value of Binzhou, Shandon is 0.22;			the values of Guangzhou is 0.205. There are some differences between districts.
$\dot{k}_J$	0.002	d^{-1}	Maturity maintenance rate coefficient
T_A	6483	K	Arrhenius temperature
T_H	311	K	Higher boundary of the tolerance range
T_L	291	K	Lower boundary of the tolerance range
T_{AH}	35000	K	Arrhenius temperature for the rate of decrease at higher boundary
T_{AL}	75000	K	Arrhenius temperature for the rate of decrease at lower boundary
E^b_H	9.19×10^{-5}	J	Maturity at birth
E^p_H	198	J	Maturity at puberty
E^j_H	1.34×10^{-4}	J	Maturity at metamorphosis
$\ddot{h}_a$	1.36×10^{-6}	d^{-2}	Weibull aging acceleration
s_G	1×10^{-4}	–	Gompertz stress coefficient
$[E_V]$	1590	J cm^{-3}	Volume-specific structural energy content

(Energy_allocated_to_dev_and_rep_Er*kR/0.001)/1E6

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