DEB 2025

Overview of typified DEB models & Tools

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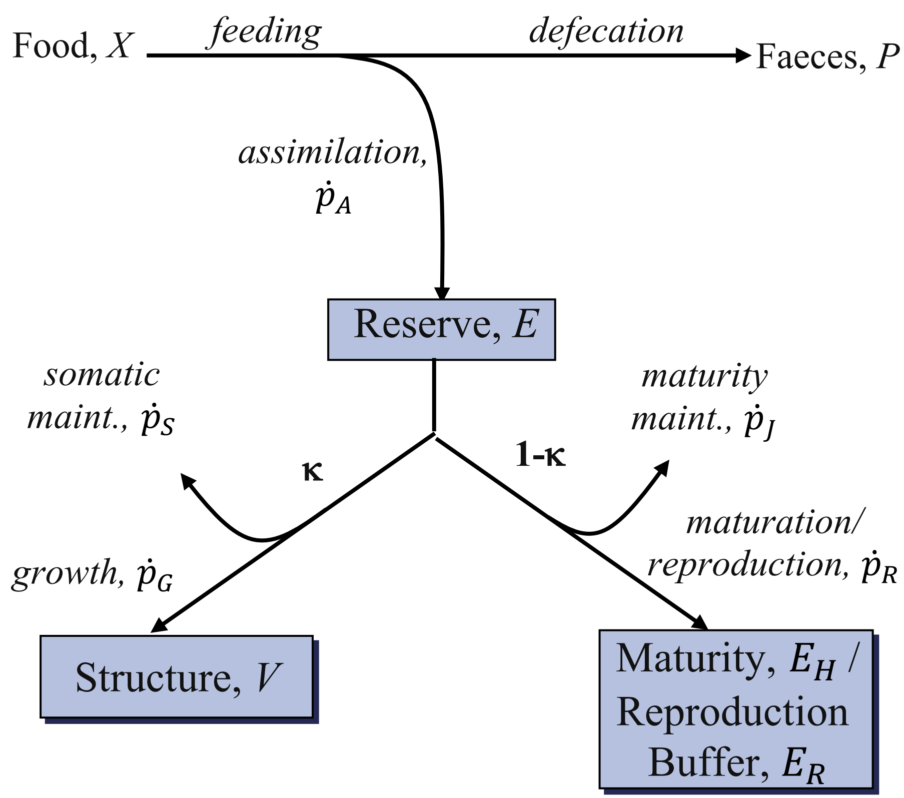
deb2025.sciencesconf.org

Lecture outline

- Overview of the standard DEB model
- Types of DEB parameters
- Deviations from the standard DEB model
- Extensions of DEB models
- AmP tool for simulating and plotting trajectories of the state of an individual and some traits in constant and dynamic environment (food/temperature)

Standard (std) DEB model

1 food type, 1 reserve, 1 structure, isomorph,
reproduces by means of eggs



Dynamics of the state variables

$$\frac{dV}{dt} = \frac{\dot{p}_G}{[E_G]}$$

$$\frac{dE}{dt} = \dot{p}_A - \dot{p}_C$$

$$\frac{dE_H}{dt} = \dot{p}_R (E_H < E_H^p)$$

$$\frac{dE_R}{dt} = \kappa_R \dot{p}_R (E_H \geq E_H^p)$$

$$\dot{p}_A = (E_H \geq E_H^b)\{\dot{p}_{Am}\}\, f(X)\, V^{2/3}$$

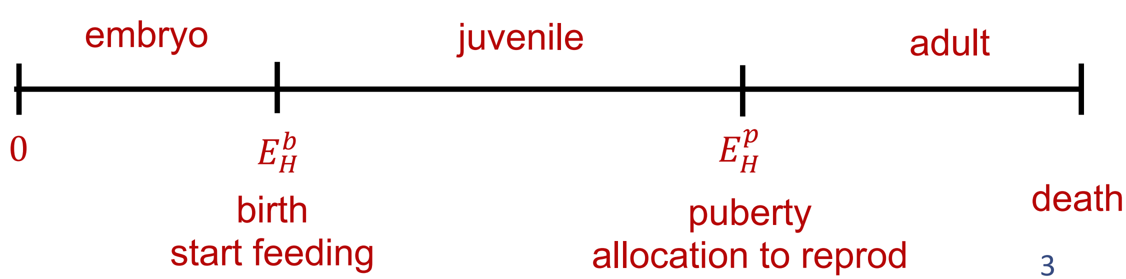
$$\dot{p}_C = E \frac{[E_G]\dot{v}/L + [\dot{p}_S]}{\kappa[E] + [E_G]}$$

$$\dot{p}_G = \kappa \dot{p}_C - \dot{p}_S$$

$$\dot{p}_S = [\dot{p}_M]V + \{\dot{p}_T\}\, V^{2/3}$$

$$\dot{p}_J = \dot{k}_J E_H$$

$$\dot{p}_R = (1-\kappa)\dot{p}_C - \dot{p}_J$$



Type of DEB parameters

- Core parameters
  - Control changes of the state variables
  - Linked to the concepts on which the model is based upon
- Auxiliary parameters
  - Convert measurements (e.g., from dry to wet mass, length to volume etc.)
  - Quantify effects of temperature on rates and time
- Primary parameters
  - Connected to a single underlying process
- Compound parameters
  - Depend on several underlying processes
  - Functions of other parameters

Primary parameters

assimilation	$\{\dot{p}_{Am}\}$	max surface-specific assim rate (J cm^{-2} d^{-1})
feeding	$\{\dot{F}_m\}$	surface- specific searching rate (l d^{-1} cm^{-2})
digestion	κ_X	digestion efficiency (-)
mobilisation	$\dot{v}$	energy conductance (cm d^{-1})
allocation	κ	allocation fraction to soma (-)
reproduction	κ_R	reproduction efficiency (-)
turnover, activity	$[\dot{p}_M]$	volume-spec. som. maint. costs (J d^{-1}cm^{-3})
heating, osmosis	$\{\dot{p}_T\}$	surface-spec. som. maint. costs (J d^{-1}cm^{-2})
development	$\dot{k}_J$	maturity maint. rate coefficient (d^{-1})
growth	$[E_G]$	specific growth for structure (J cm^{-3})
life cycle	E_H^b	maturity at birth (J)
life cycle	E_H^p	maturity at puberty (J)
aging	$\dot{h}_a$	Weibul aging acceleration (d^{-2})
aging	s_G	Gompertz stress coefficient (-)

Examples of compound parameters

$$[E_m] = \frac{\{\dot{p}_{Am}\}}{\dot{v}}$$ max reserve density

$$L_m = \frac{\kappa\{\dot{p}_{Am}\}}{[\dot{p}_M]}$$ max structural length

Auxiliary parameters

Conversion parameters

δ_M	shape coefficient (-)
$d_O = (d_X\ d_V\ d_E\ d_P)$	specific densities (g/cm^3)
$\mu_O = (\mu_X\ \mu_V\ \mu_E\ \mu_P)$	chemical potentials (organics) (J/mol)
$\mu_M = (\mu_C\ \mu_H\ \mu_O\ \mu_N)$	chemical potentials (minerals) (J/mol)
$n_O = (n_X\ n_V\ n_E\ n_P)$	chemical indices (organics) (-)
$n_M = (n_C\ n_H\ n_O\ n_N)$	chemical indices (minerals) (-)
$w_O = (12\ 1\ 16\ 14)$	molecular weights (g/mol)

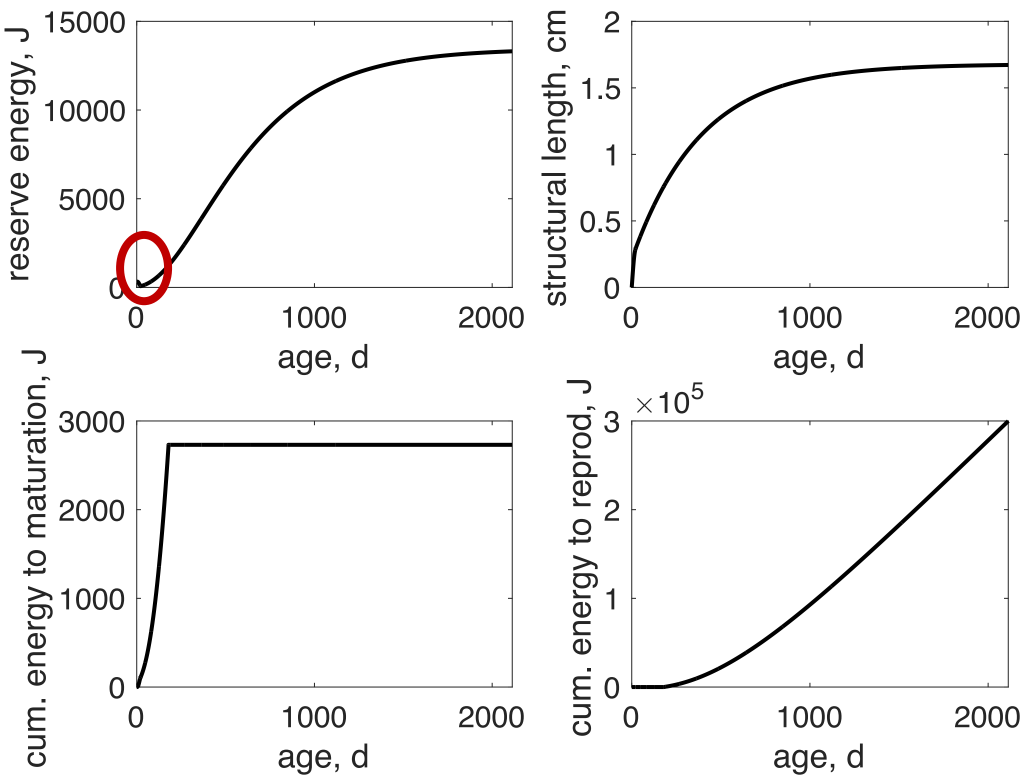
O	organics
M	minerals
X	food
V	structure
E	reserve
P	faeces
C	CO_2
H	H_2O
O	O_2
N	N-waste

Temperature parameters

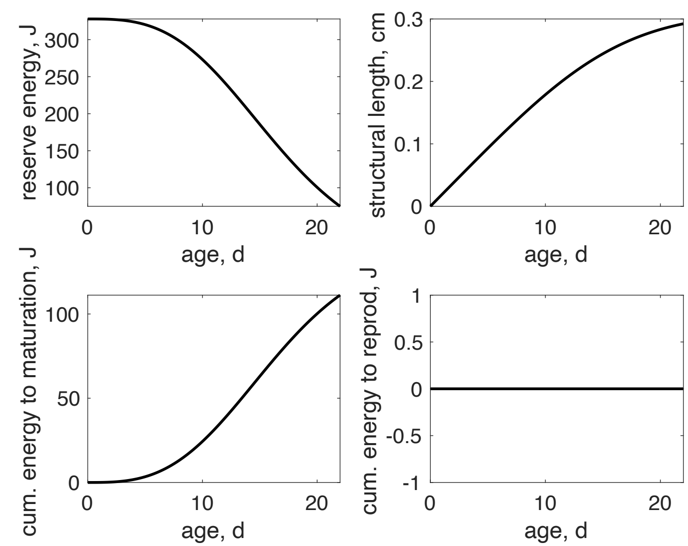
T_{ref}	reference temperature (293 K)
T_A	Arrhenius temperature
T_L, T_H	temperature tolerance range
T_{AL}, T_{AH}	Arrhenius temperatures for transitions to inert state

Individual Dynamics
from start of development to death by aging

Constant environment



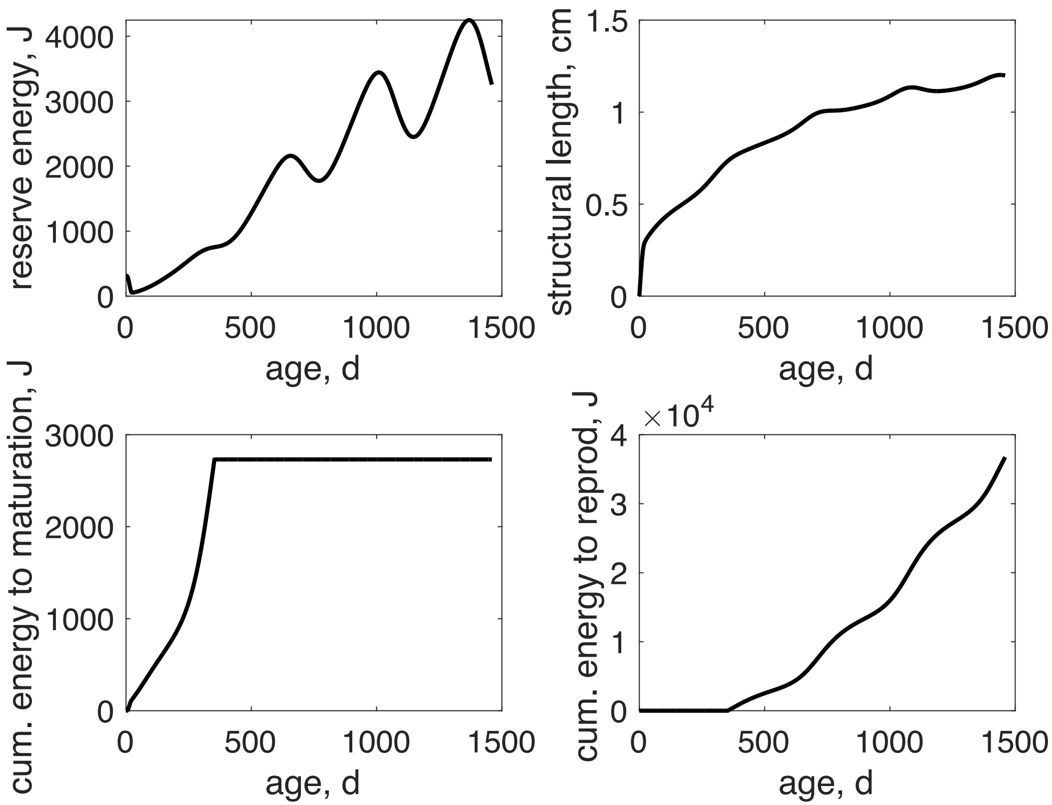
Embryo dynamics



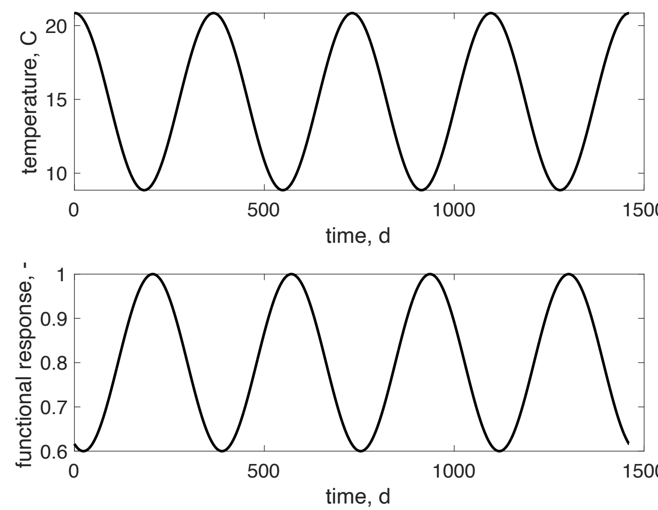
Hippocampus whitei (White's seahorse)

Individual Dynamics

Varying environment



Temp and food variation



Life Stages

Morphological life stages

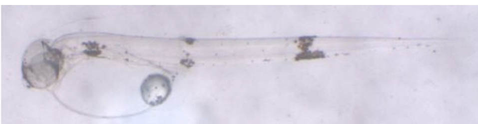
refer to the physical or structural changes that an organism undergoes throughout its life cycle. E.g., egg, larva, pupa, and imago in insects tadpole and frog in amphibians

Functional life stages

refer to functional or physiological changes that occur during the life cycle of an organism. E.g. embryo, juvenile, adults

Deviations from the std DEB model

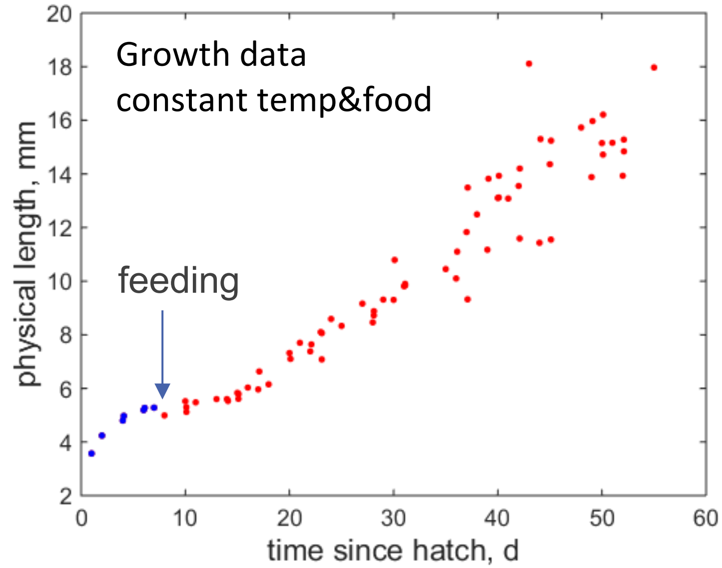
European sea bass, *Dicentrarchus labrax*

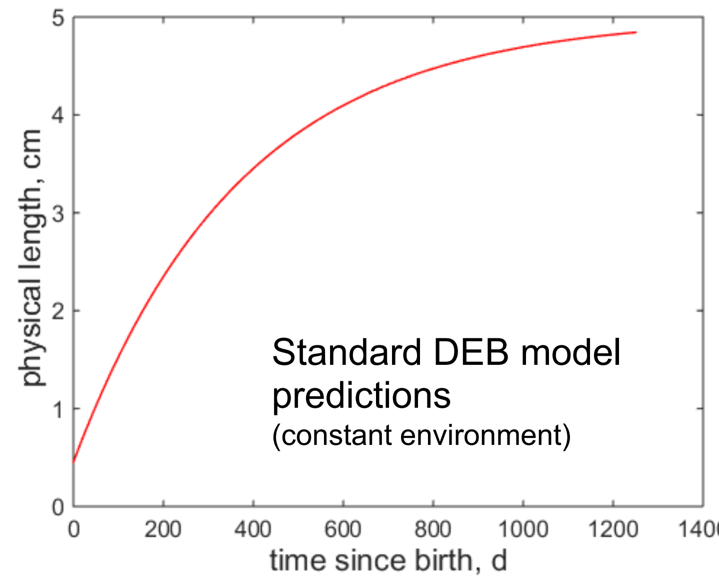


15dph

35 dph (fins)

juvenile

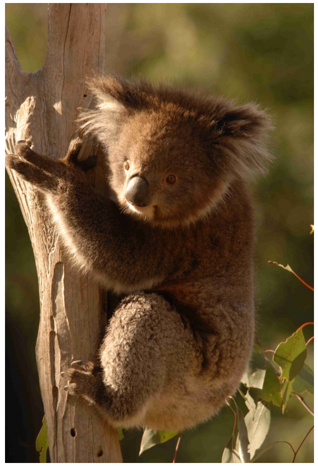




Life stages: egg, larvae, juvenile, adult

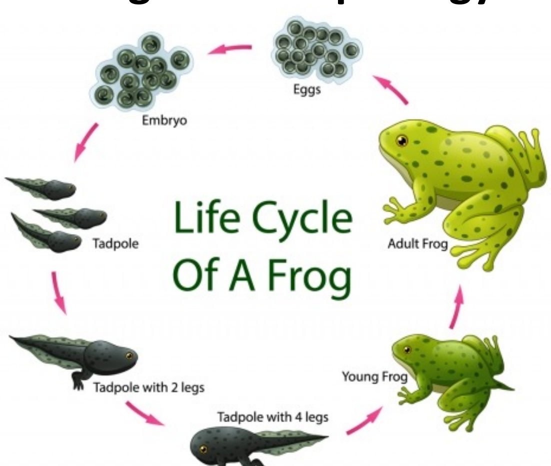
Deviations from the std DEB model

Fetal development



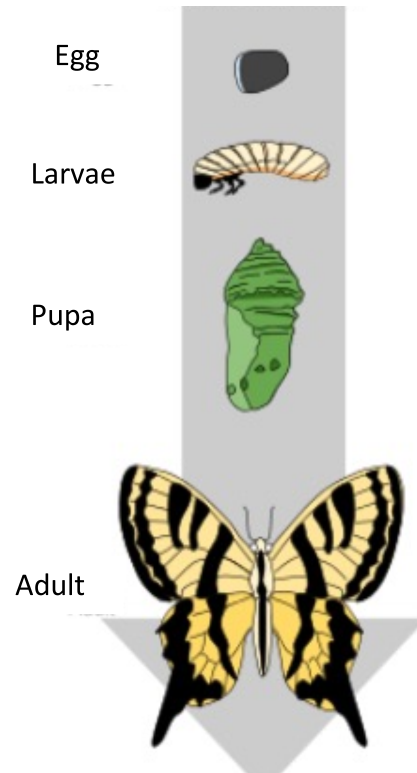
Koala
Phascolarctos cinereus
Author: Bas Kooijman

Changes in morphology

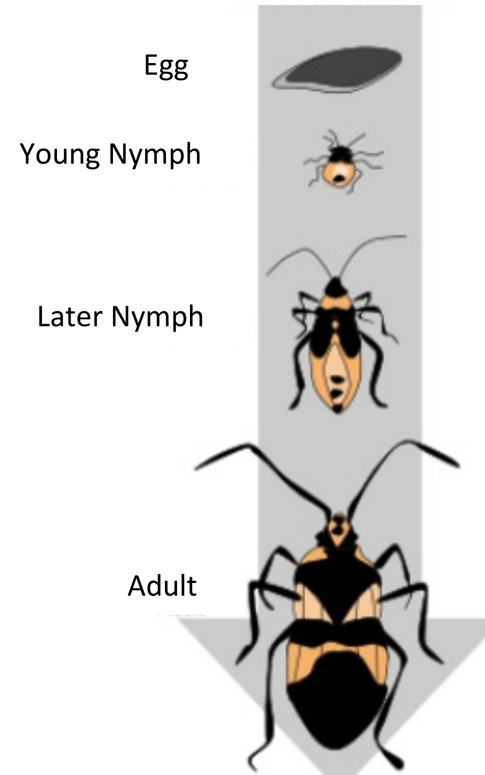


(Source: Dualororua)

Holometabolous



Hemimetabolous



Typified Models in AmP

- To accommodate complex life-cycles, various forms of metabolic acceleration and fetal development different models of DEB theory have been applied to different organisms.
- All are related and consistent with the DEB theory.
- They are extensions of the standard DEB model.
- For the purpose of standardizing parameter estimation some extensions of the standard DEB model have been formalized and are called “typified” models.

s-models
- std
- stf
- stx
- ssj
- sbp

a-models
- abj
- asj
- abp

h-models
- hep
- hax
- hex

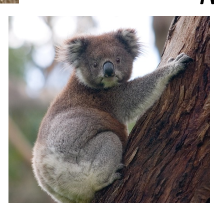
s-models

Assume isomorphy throughout the full life cycle: **surface area $\propto$ volume$^{2/3}$**

s-models	Description	%entries in AmP
std	standard DEB model with egg development	38.42%
stf	std with foetal development	0.85%
stx	stf with baby stage until weaning x (b<x<p)	12.23%
ssj	std with non-feeding stage between s and j (b<s<j<p)	0.25%
sbp	std with growth ceasing at puberty	0.07%

Squalus acantias

std



Phascolarctos cinereus

stx

Monachus monachus

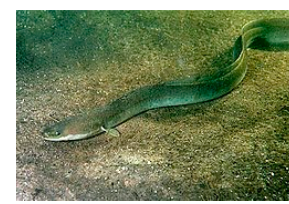
stx

Oedura_monilis

stf

Tigriopus brevicornis

sbp



Oedura_monilis

ssj

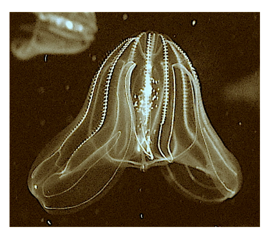
a-models

Assume isomorphy, but during part of the life cycle metabolism accelerates following the rules for V1-morphy **surface area ∝ volume**

a-models	Description	%entries in AmP
abj	std with acceleration between birth b and metamorphosis j (b<j<p)	47.46%
asj	abj with delayed acceleration starting at s (b<s<j<p)	0.07%
abp	abj with growth ceasing at puberty	0.27%

Dicentrarchus labrax
abj

Mytilus edulis
abj



Mnemiopsis leidyi
asj

Eurytemora affinis
abp

Locusta migratoria
abp

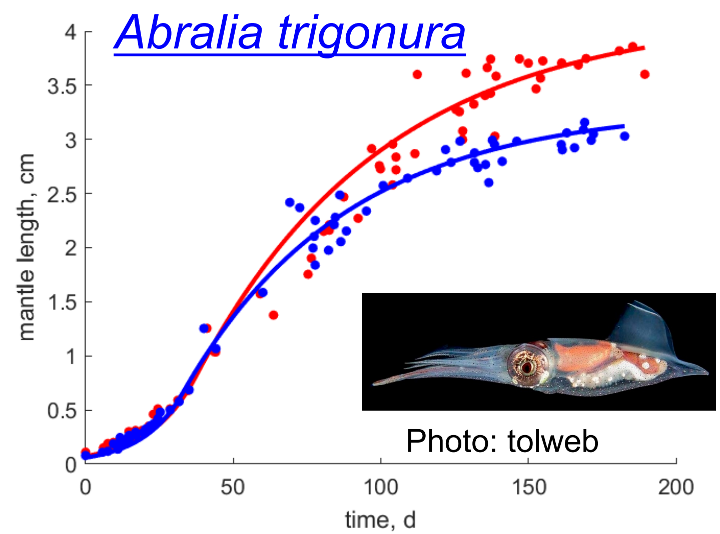
M acceleration: modelled with a-models

M-type acceleration is observed in most invertebrate species with morphological metamorphosis, but also to some taxa without.

Recognize M acceleration by upcurving of length-at-age at constant food and temperature.

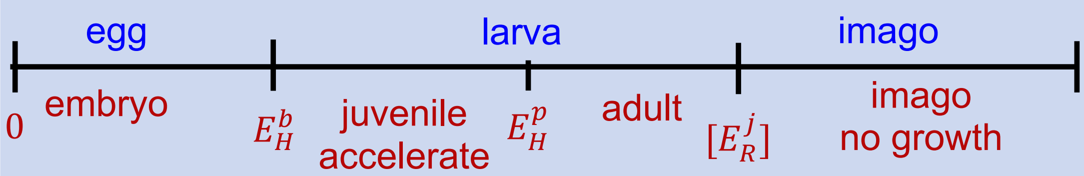
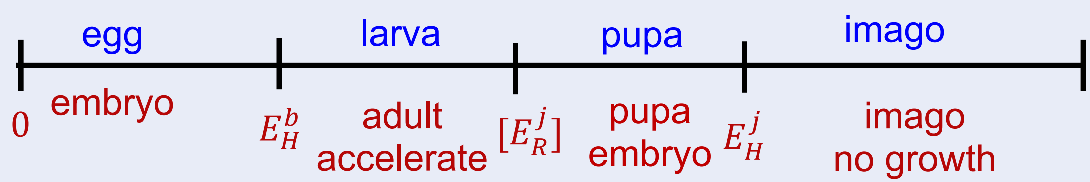
Surface area proportional to volume during M acceleration. This affects both specific assimilation $\{\dot{p}_{Am}\}$ and energy conductance $\dot{v}$, which increase with length.

The end of acceleration is controlled by the maturity level passing a threshold value.



h-models

h-models are as a-models, but with extra life stages (as found in insects)

<table>
<tr><th>h-models</th><th>Description</th><th>%entries in AmP</th></tr>
<tr><td>hep</td><td>
</td><td>0.15%</td></tr>
<tr><td>hex</td><td>
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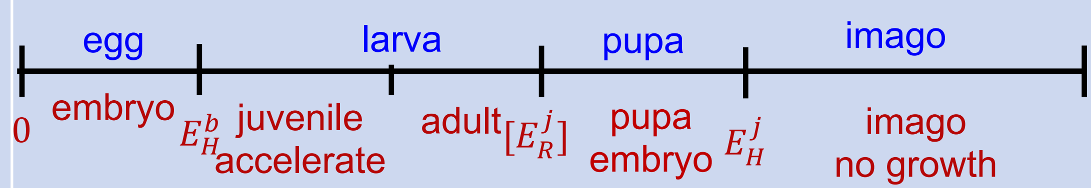
<tr><td>hax</td><td>
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AmP tool for simulating and plotting states and traits

species: species_name
tT: time-temperature
tf: time-functional response

https://amptool.debtheory.org/docs/index.html

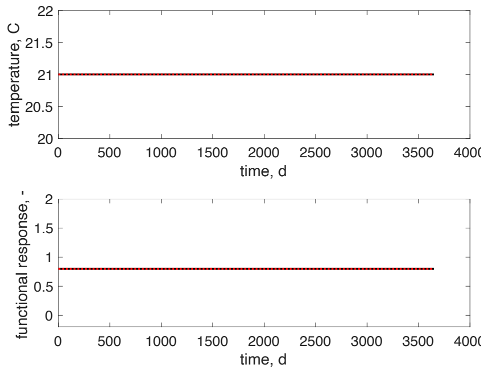
simu_my_pet.m
calls
get_indDyn_mod.m

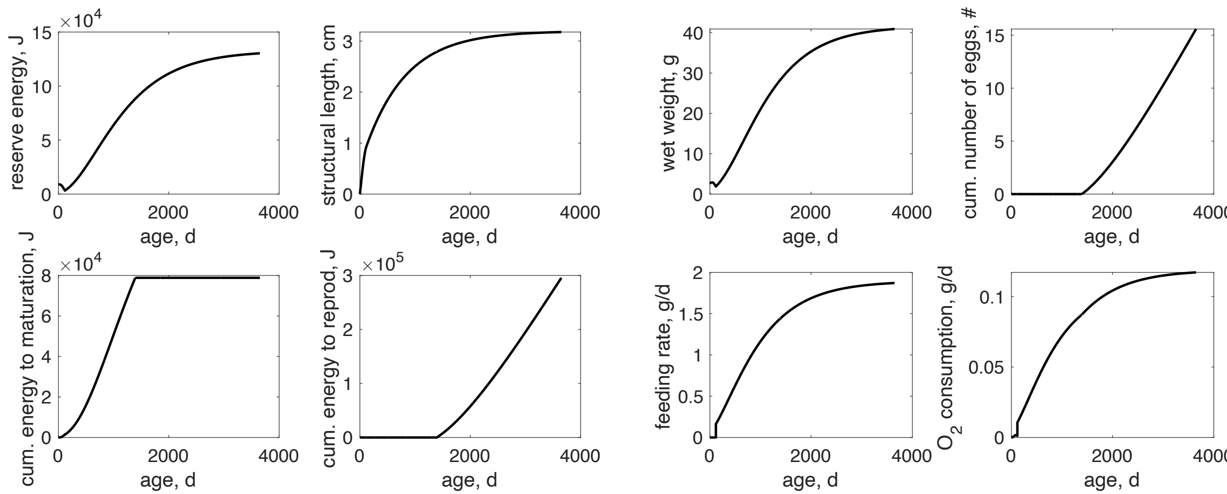
Plots: Environmental variables
State variables: E, L, E_H, E_R
Observable quantities: weight, fecundity, feeding, O2 consumption
Powers
Table with age, weight at life events

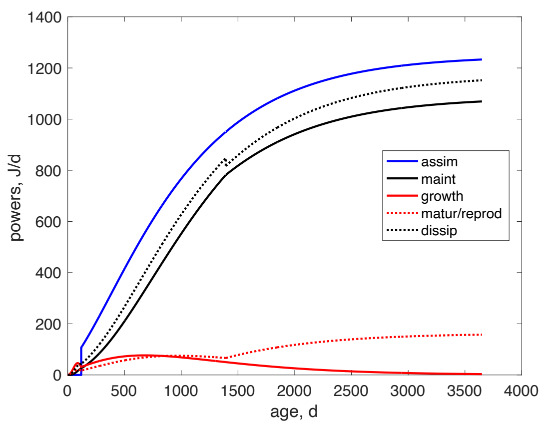
The code supports the `std`, `sbp`, and all `a`-models
The functions are in AmPtool/trajectories

Megalobulimus mogianensis (snail)

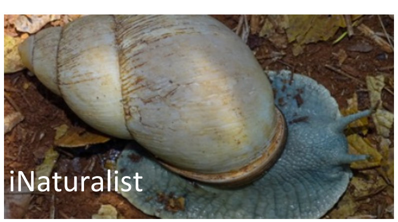
```
simu_my_pet('Megalobulimus_mogianensis', [0 C2K(21); 10*365 C2K(21)],0.8)
```





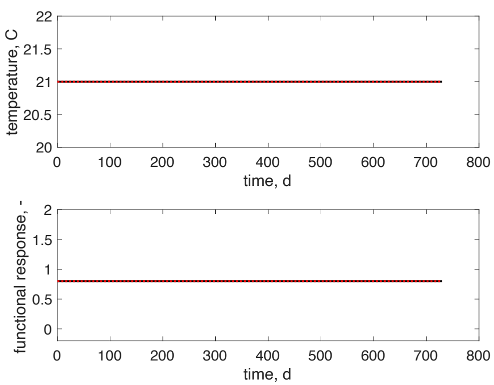


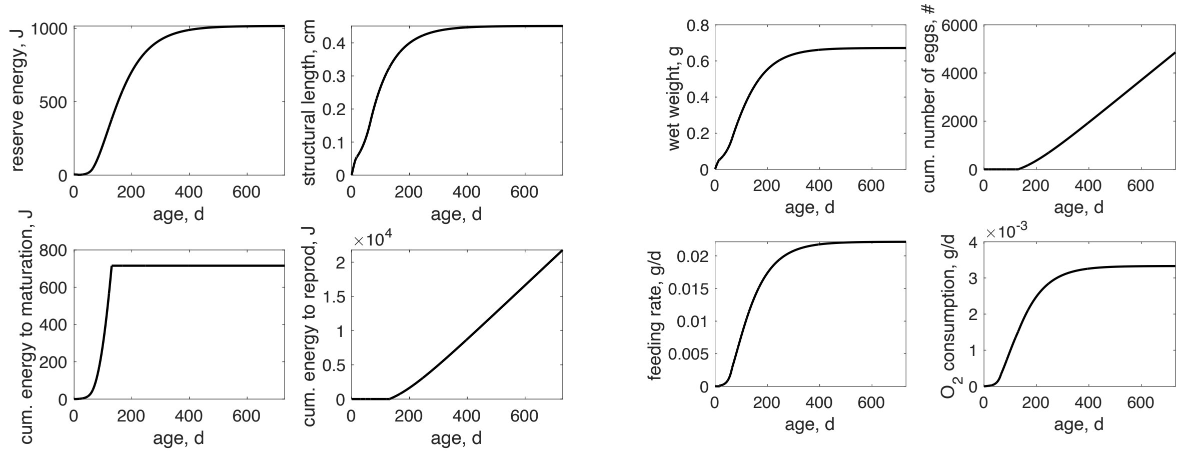
description; symbol (units)	values at T&f (event function)	values at mean T&f (DEBtool functions)
age at birth; a_b (d)	118.7186	118.731
age at puberty; a_p (d)	1392.4776	1392.4901
life span; a_m (d)	13916.0466	13916.0466
struc length at birth; L_b (cm)	0.9351	0.9351
struc length at puberty; L_p (cm)	2.7888	2.7888
ultimate length; L_i (cm)	NaN	3.1967
wet weight at birth; Ww_b (g)	1.7803	1.7803
wet weight at puberty; Ww_p (g)	47.2259	47.2259
ultimate wet weigh; Ww_i (g)	NaN	71.1273

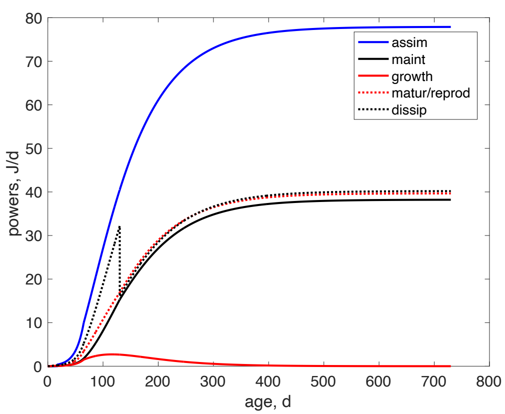


Oryzias latipes (medaka)

```
simu_my_pet('Oryzias_latipes', [0 C2K(21); 2*365 C2K(21)],0.8)
```





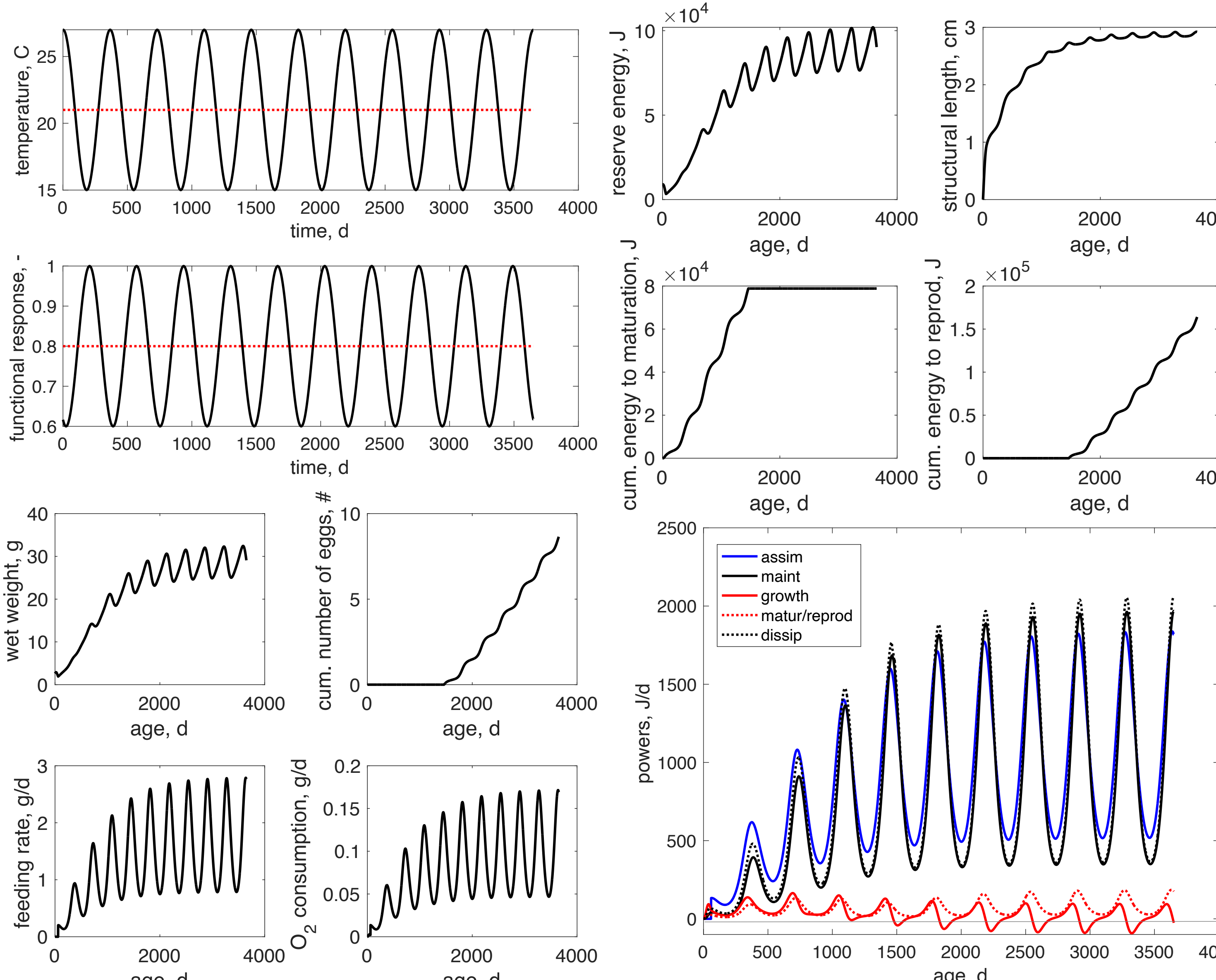


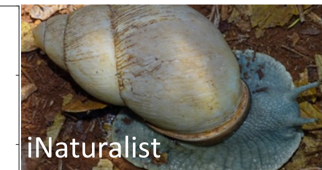
description; symbol (units)	values at T&f (event function)	values at mean T&f (DEBtool functions)
age at birth; a_b (d)	17.3779	17.4055
age at metamorphosis; a_j (d)	64.9835	65.0141
age at puberty; a_p (d)	130.2999	130.5187
life span; a_m (d)	1342.5696	1342.5696
struc length at birth; L_b (cm)	0.053987	0.053989
struc length at metamorphosis; L_j (cm)	0.1612	0.1612
struc length at puberty; L_p (cm)	0.32525	0.32733
ultimate length; L_i (cm)	NaN	0.45104
wet weight at birth; Ww_b (g)	0.00053595	0.00053588
wet weight at metamorphosis; Ww_j (g)	0.014264	0.014263
wet weight at puberty; Ww_p (g)	0.11717	0.11943
ultimate wet weight; Ww_i (g)	NaN	0.31246

Examples of variable T and f

```
% Define simulation time (in days) over 10 years
t_end = 10 * 365; % total time in days
n_points = 5000; % number of time steps
t = linspace(0, t_end, n_points)';

% Environmental parameters
T_mean_C = 21; % mean temperature in °C
T_amp = 6; % amplitude of seasonal variation in K
T_phase_shift = 90; % phase shift in days

% Functional response parameters
f_mean = 0.8; % average feeding level
f_amp = 0.2; % amplitude of variation
f_phase_shift = 250; % phase shift in days

% Generate environmental profiles
T_K = C2K(T_mean_C) + T_amp * sin(2 * pi * (t + T_phase_shift) / 365);
f = f_mean + f_amp * sin(2 * pi * (t + f_phase_shift) / 365);

% Combine time and environmental data
tT = [t, T_K]; % Time-temperature profile (K)
tf = [t, f]; % Time-functional response profile

% Run the simulation
simu_my_pet('Megalobulimus_mogianensis', tT, tf);
```

Megalobulimus mogianensis (snail)



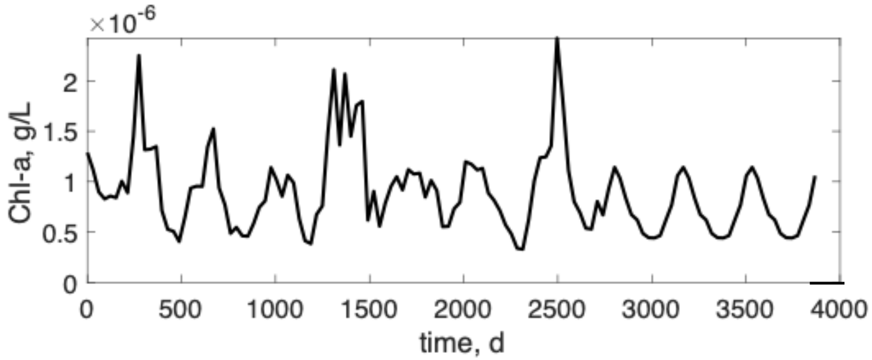


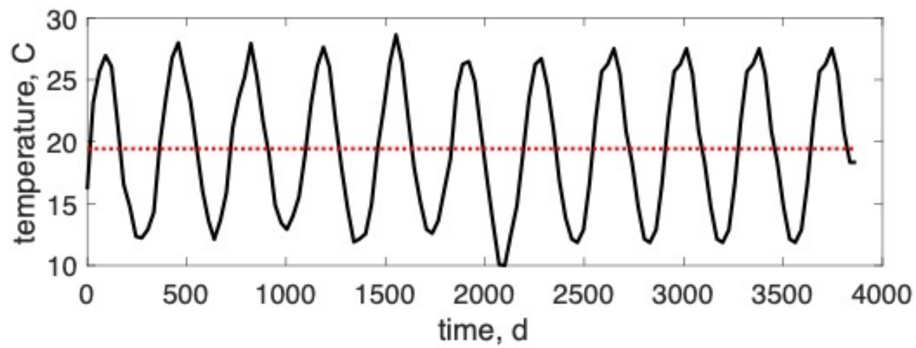
Megalobulimus mogianensis (snail)

description; symbol (units)	values at T&f (event function)	values at mean T&f (DEBtool functions)
age at birth; a_b (d)	59.0791	101.4495
age at puberty; a_p (d)	1462.846	1189.9145
life span; a_m (d)	13913.7321	13913.7321
struc length at birth; L_b (cm)	0.9351	0.9351
struc length at puberty; L_p (cm)	2.7312	2.7888
ultimate length; L_i (cm)	NaN	3.1966
wet weight at birth; Ww_b (g)	1.7803	1.7803
wet weight at puberty; Ww_p (g)	41.4613	47.2229
ultimate wet weigh; Ww_i (g)	NaN	71.1158

Pinna nobilis (Noble pen shell)

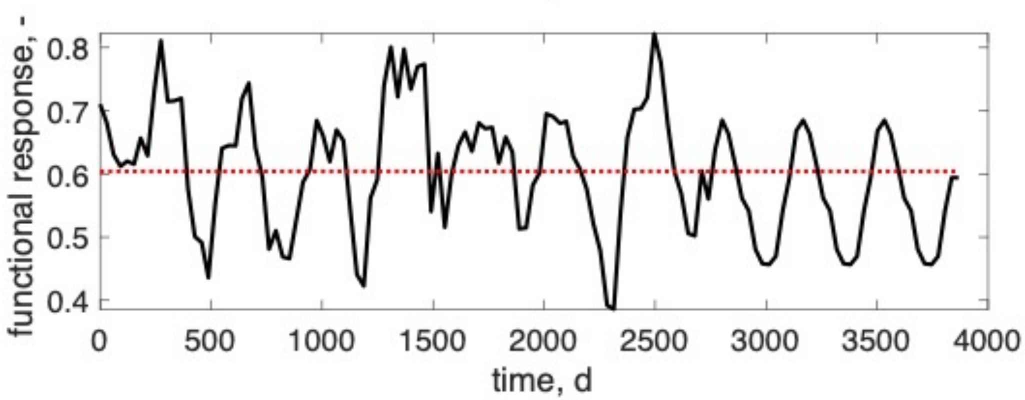
Temperature and Chl-a data from the Thermaic gulf in Greece



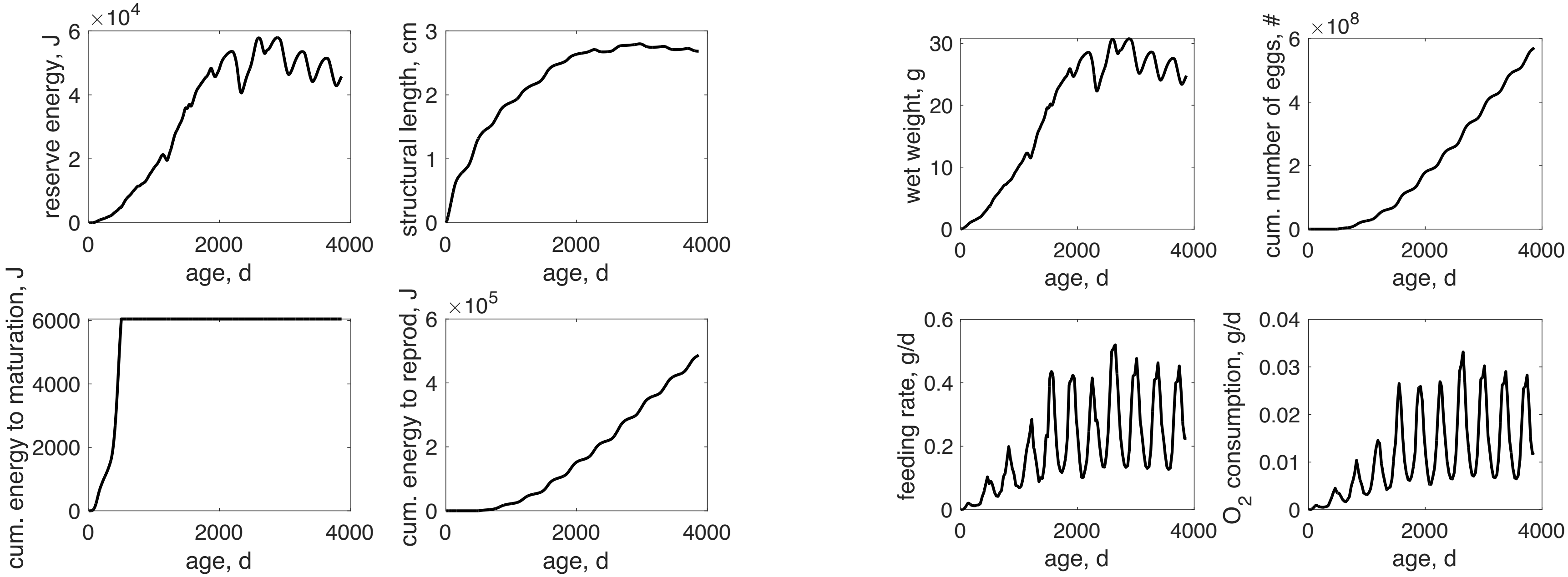


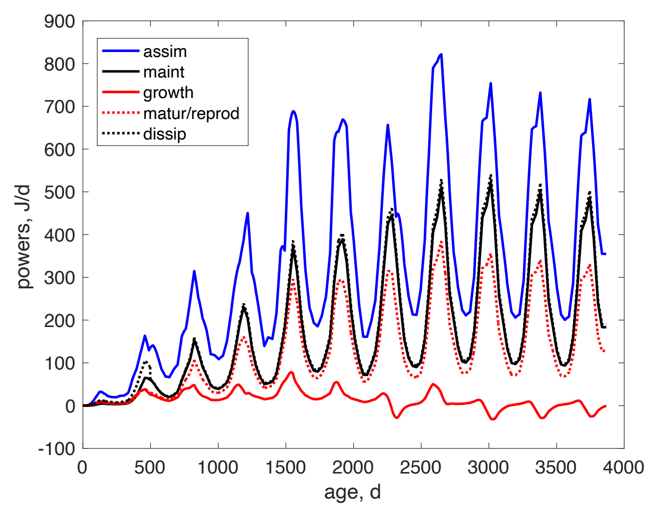
$$f = \frac{X}{K + X}$$

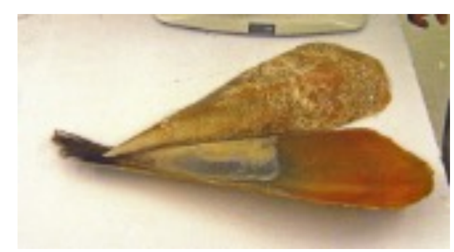
Half saturation constant
K = 5.25 10^{-7} g/L



Pinna nobilis (Noble pen shell)







Pinna nobilis (Noble pen shell)

description; symbol (units)	values at T&f (event function)	values at mean T&f (DEBtool functions)
age at birth; a_b (d)	3.3825	2.2186
age at metamorphosis; a_j (d)	9.3609	7.0539
age at puberty; a_p (d)	497.9067	560.4616
life span; a_m (d)	3583.4854	3583.4854
struc length at birth; L_b (cm)	0.0048664	0.0048664
struc length at metamorphosis; L_j (cm)	0.014084	0.014083
struc length at puberty; L_p (cm)	1.3181	1.3275
ultimate length; L_i (cm)	NaN	3.0907
wet weight at birth; Ww_b (g)	2.6769e-07	2.6769e-07
wet weight at metamorphosis; Ww_j (g)	7.0892e-06	6.4876e-06
wet weight at puberty; Ww_p (g)	4.6704	5.4336
ultimate wet weigh; Ww_i (g)	NaN	68.5765

Code limitations

The get_indDyn_mod.m

- does not include spawning
  - Reserve allocated to reproduction is collected in the **reproduction buffer**
  - Species-specific buffer handling rules for the conversion to eggs or foetuses
- wet weight does not include reproduction buffer
- physical length is not presented
  - Can be obtained from structural length if the shape coefficient is specified: $L_w = \frac{L}{\delta_{\mathrm{M}}}$

Code limitations

Starvation in DEB context

Starvation rules depend on species and environmental conditions

- When mobilized reserves cannot meet somatic maintenance (i.e. $\kappa\dot{p}_C - \dot{p}_S < 0$) different rules may apply
    - somatic maintenance can be paid from the reproduction buffer
    - **shrink in structural mass to pay the somatic maintenance** (this implemented in the code)
- When mobilized reserves cannot meet maturity maintenance (i.e. $(1-\kappa)\dot{p}_C - \dot{p}_J < 0$)
    - Rejuvenation may occur

Death-rules

- If shrinking is allowed, death by starvation occurs when shrinking of structure exceeds a given fraction of the structure at the onset of ceasing growth
- When the reserve is depleted to a certain extent, we can assume that starvation-induced death strikes

Thank you for your attention!!!

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