



Trophic ecology and Dynamic Energy Budget (DEB) theory:

Concepts, Recent developments and Perspectives

Laure Pecquerie & Sébastien Lefebvre



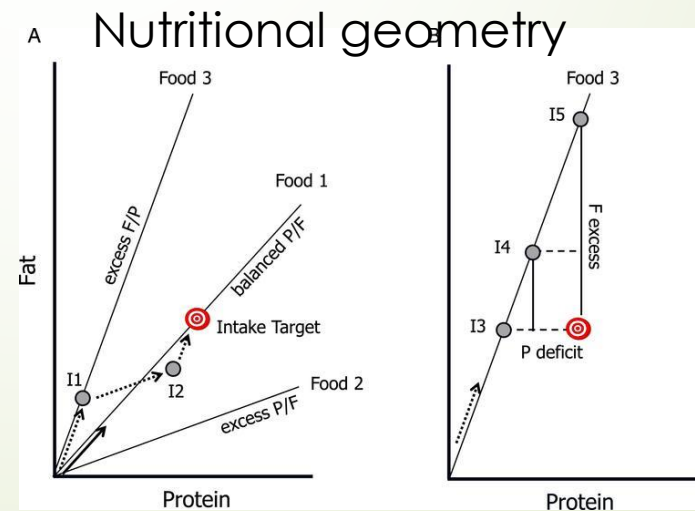
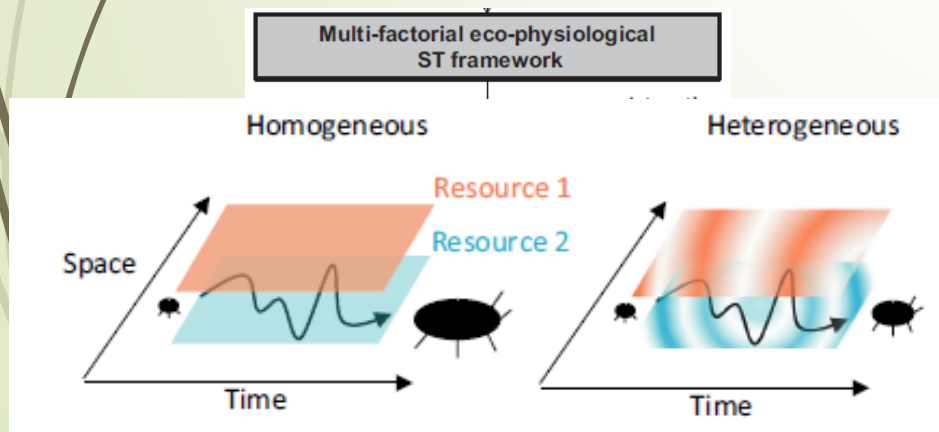
Laure Pecquerie



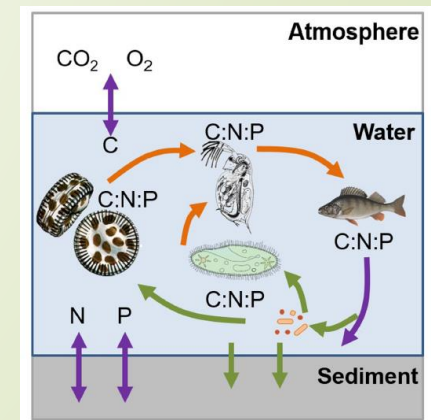
She apologizes....
but the stork knocked at the door

Outline of the presentation

- Origin of DEB theory
- Properties of the standard DEB model
- Usual applications in trophic ecology
- Standard DEB and stoichiometry (and isotopes)
- DEB extensions and links with nutritional geometry, ecological stoichiometry, and scale theory framework
- Beyond the individual (population and community)
- Challenges and perspectives in trophic ecology

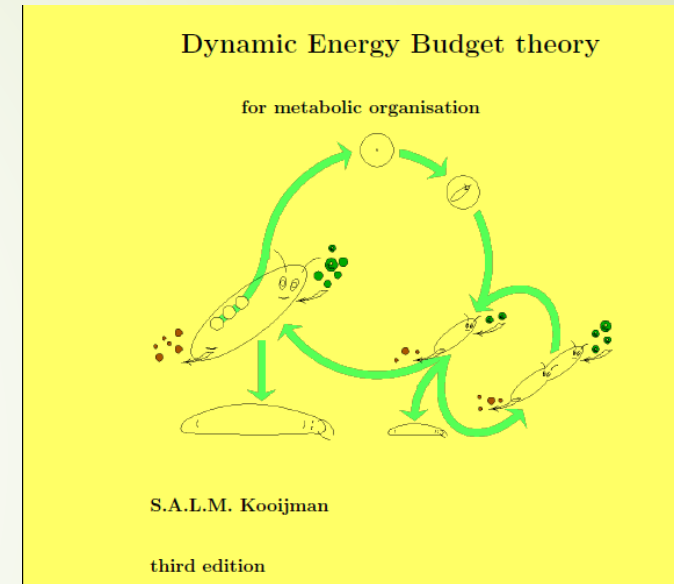


Ecological stoichiometry



DEB is a theory unifying metabolic organisation

- ▶ Common metabolic processes: Not species specific
 - ▶ Common patterns in Feeding, Growth, Reproduction, Maturation (development), Maintenance....
 - ▶ Whatever Life stages (embryo, juveniles and adults)
 - ▶ Whatever stoichiometry of organisms
 - ▶ From individuals to ecosystems (microbes, plants and animals)
-
- ▶ Originates from ecotoxicology problems: Toxicants may decrease some aspects of the energy and mass budget of an organism (feeding rate, maintenance, reprod rate....), so where does this energy goes? (Kooijman and Metz, 1984)



Kooijman, 2010



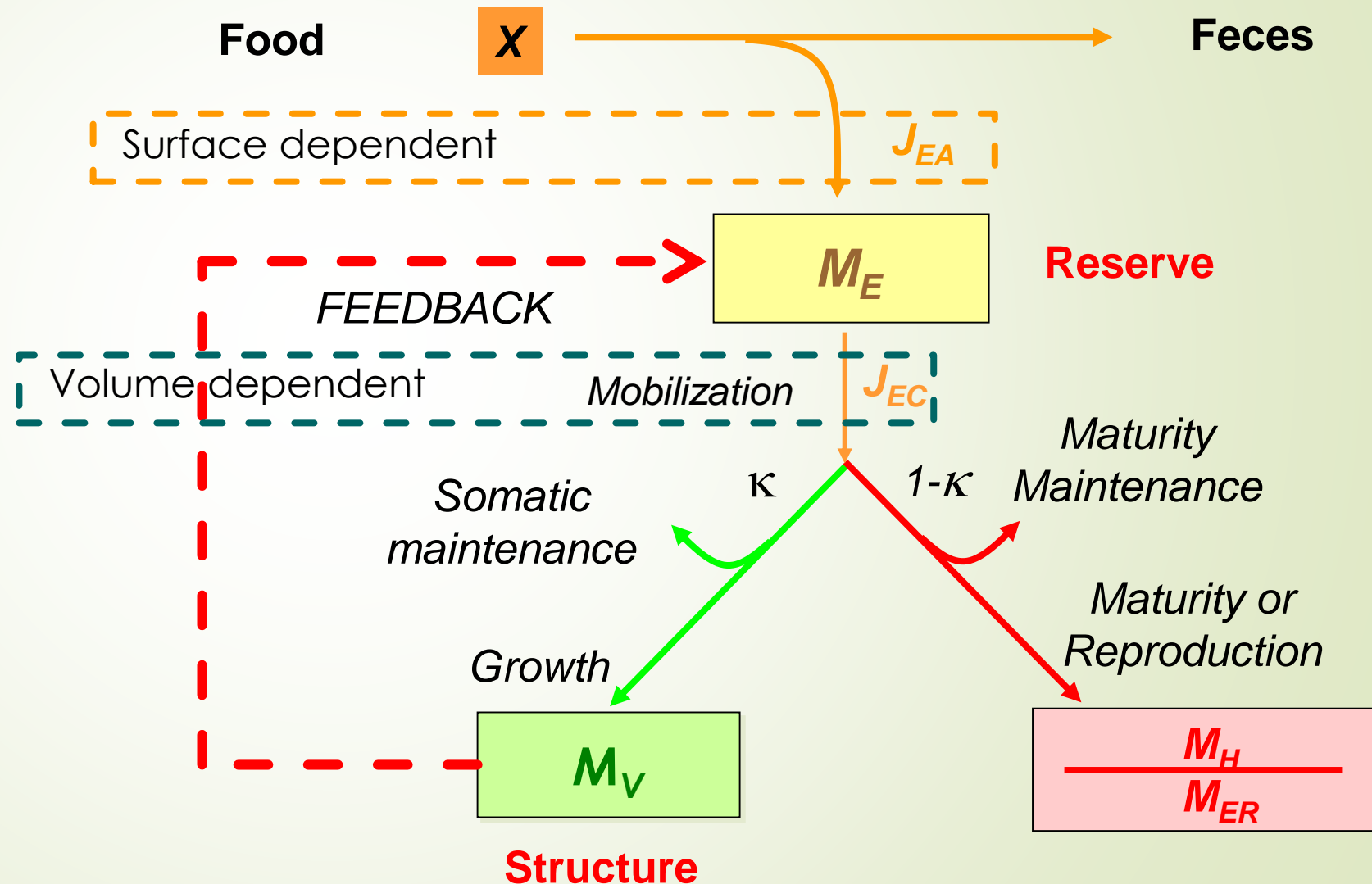
Standard DEB

Standard DEB: (average) individual level

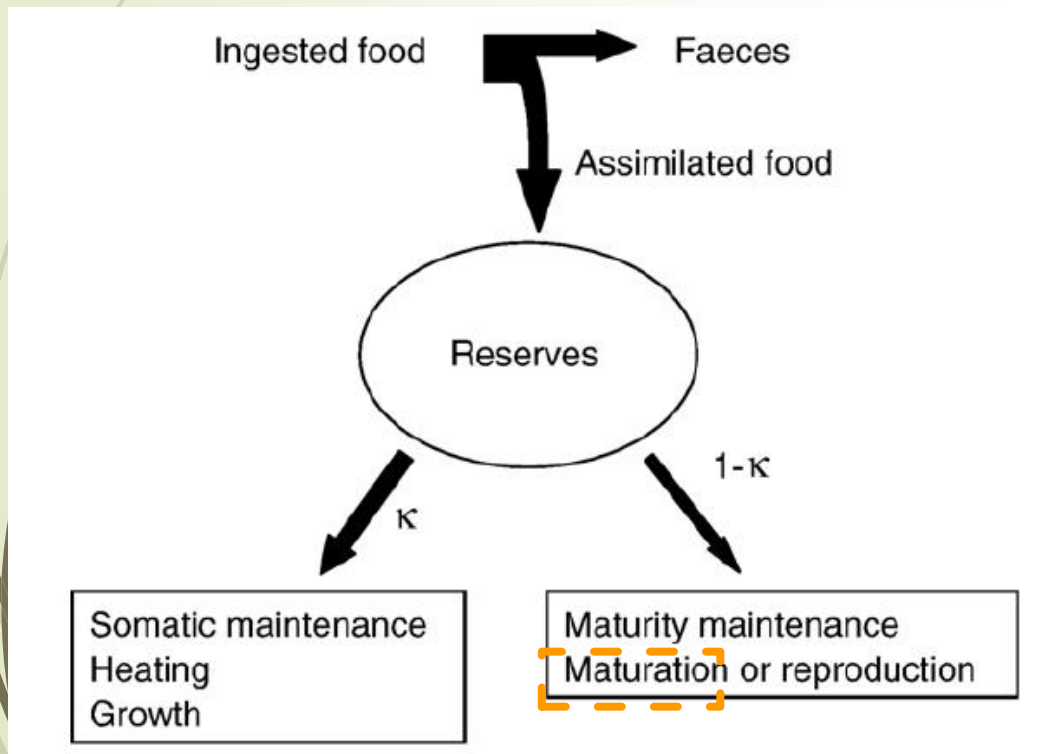
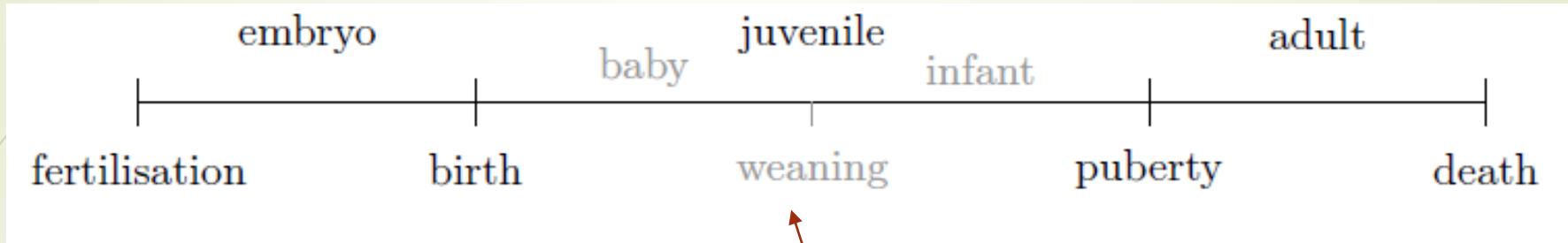
- 4 ODEs (+ 2 for aging)
- Each arrow is a flux
- 12 basic parameters

- Main properties
 - Reserve: fluctuating environment
 - Asymptotic length
 - Full Life cycle
 - Full mass and energy budget
 - All rates are temperature dependent

- Size=fct°(M_v)
- Weight=fct°(M_v & M_e & M_{er})
- Currency is general compounds



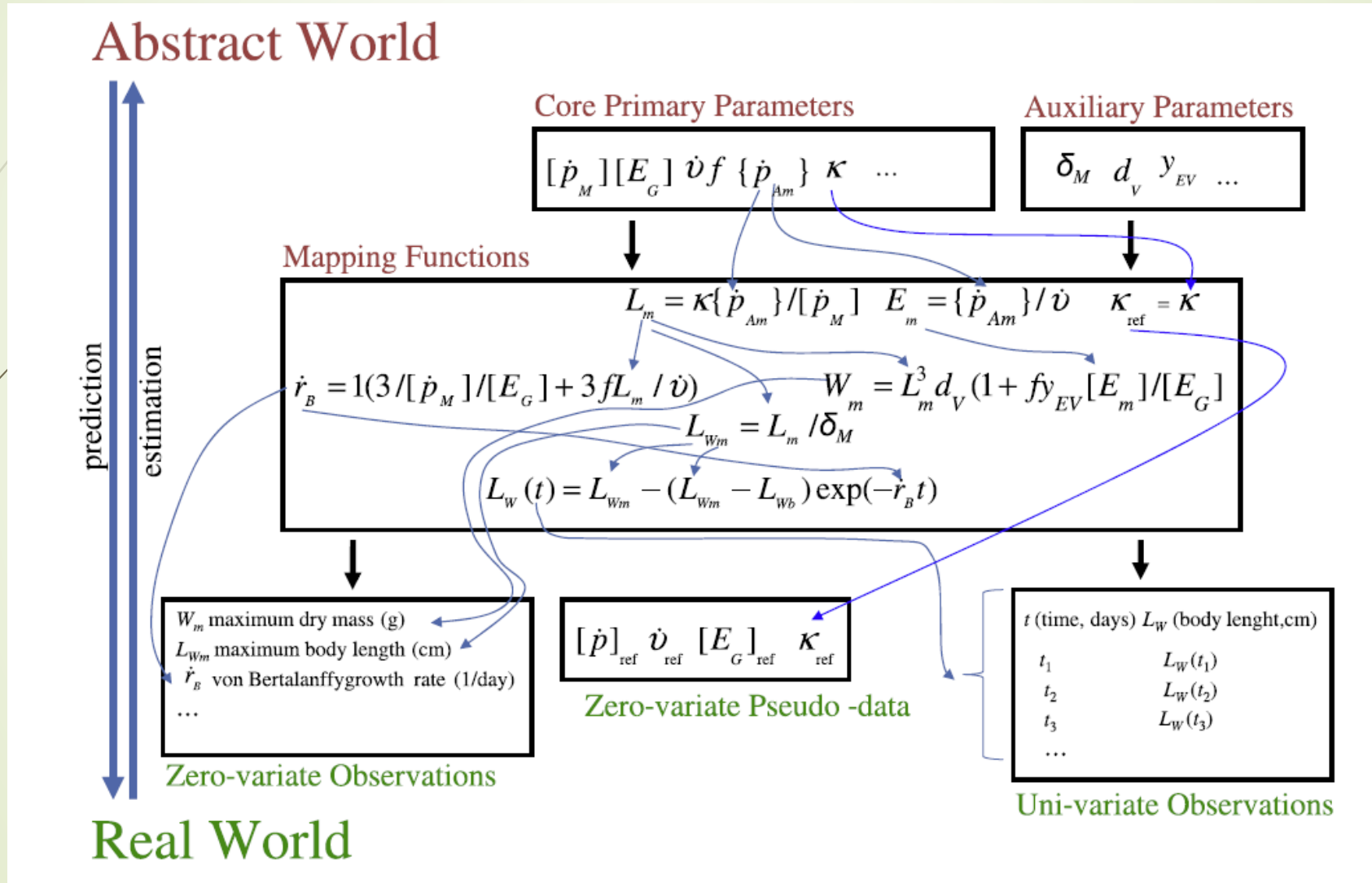
Standard DEB: life cycle



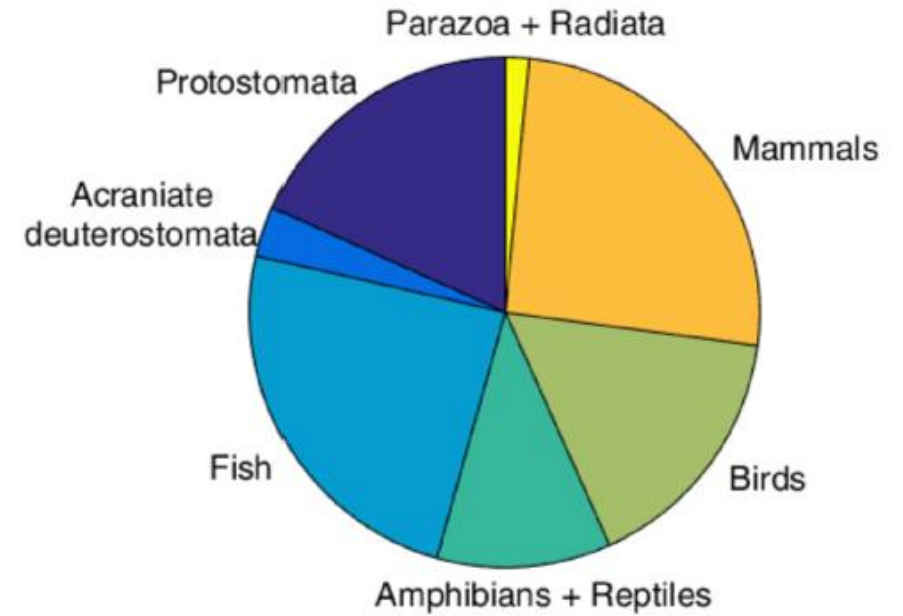
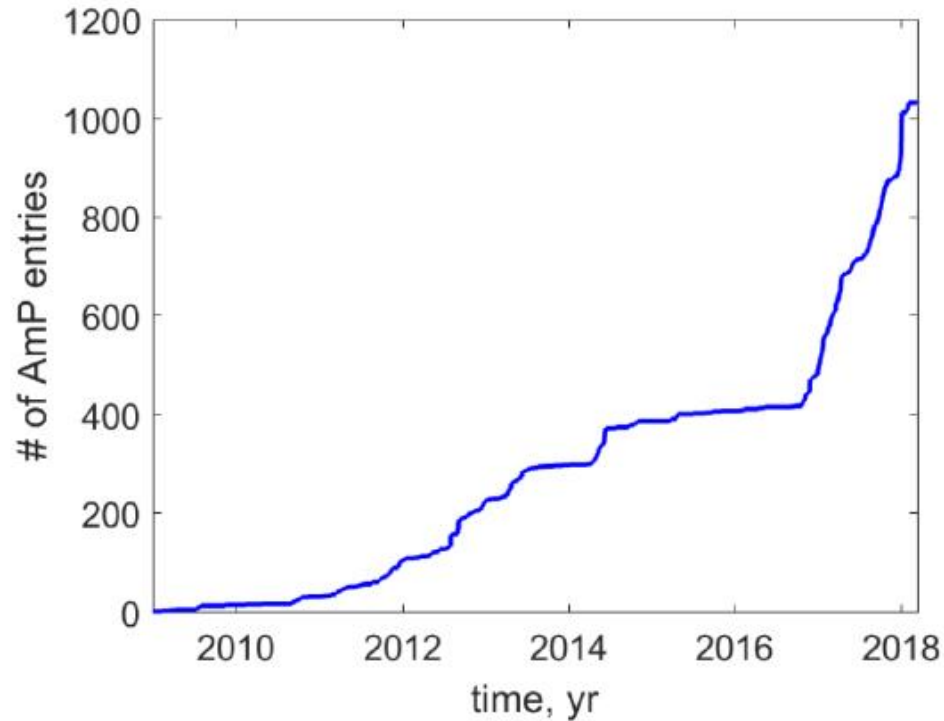
Predictions are life history traits:
Age, length weight at birth,
puberty, death....

Thresholds!

Calibration: co-variation method



Add my pet portal

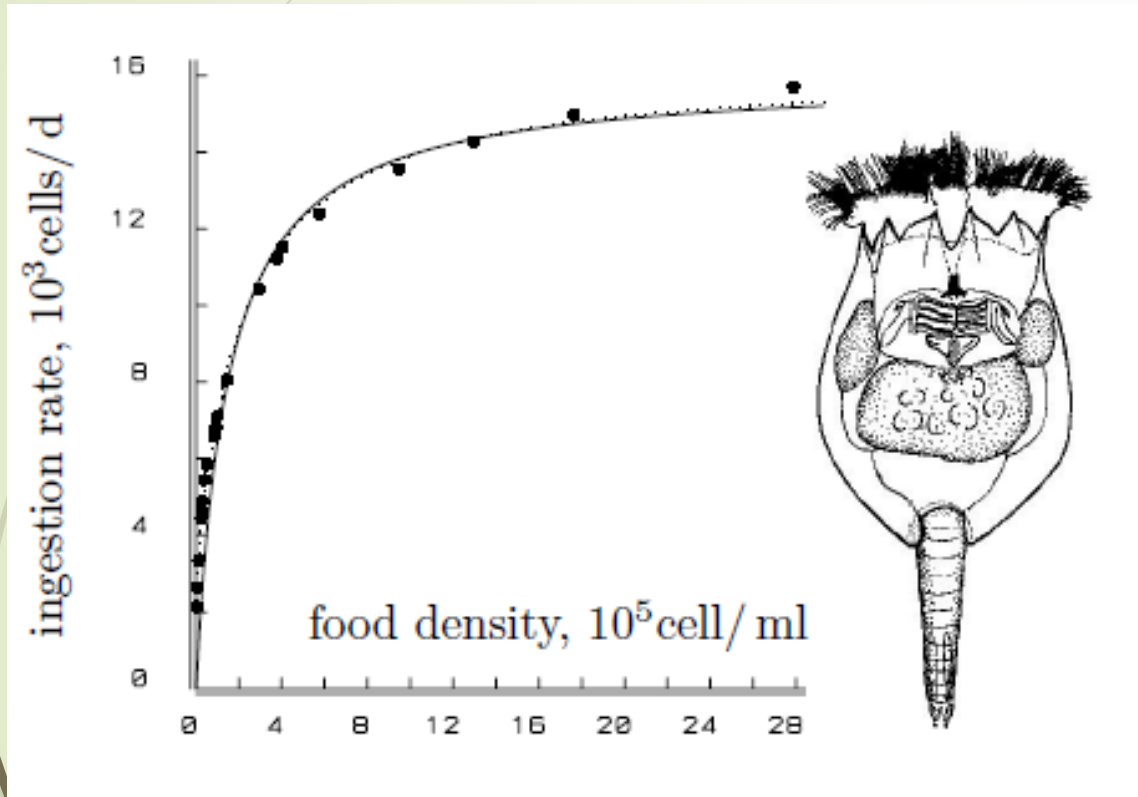


- ▶ Zoo of parameters for >1000 species (3/4 vertebrates)
- ▶ >120 researchers



Usual applications in trophic ecology

Food ingestion: scaled functional response

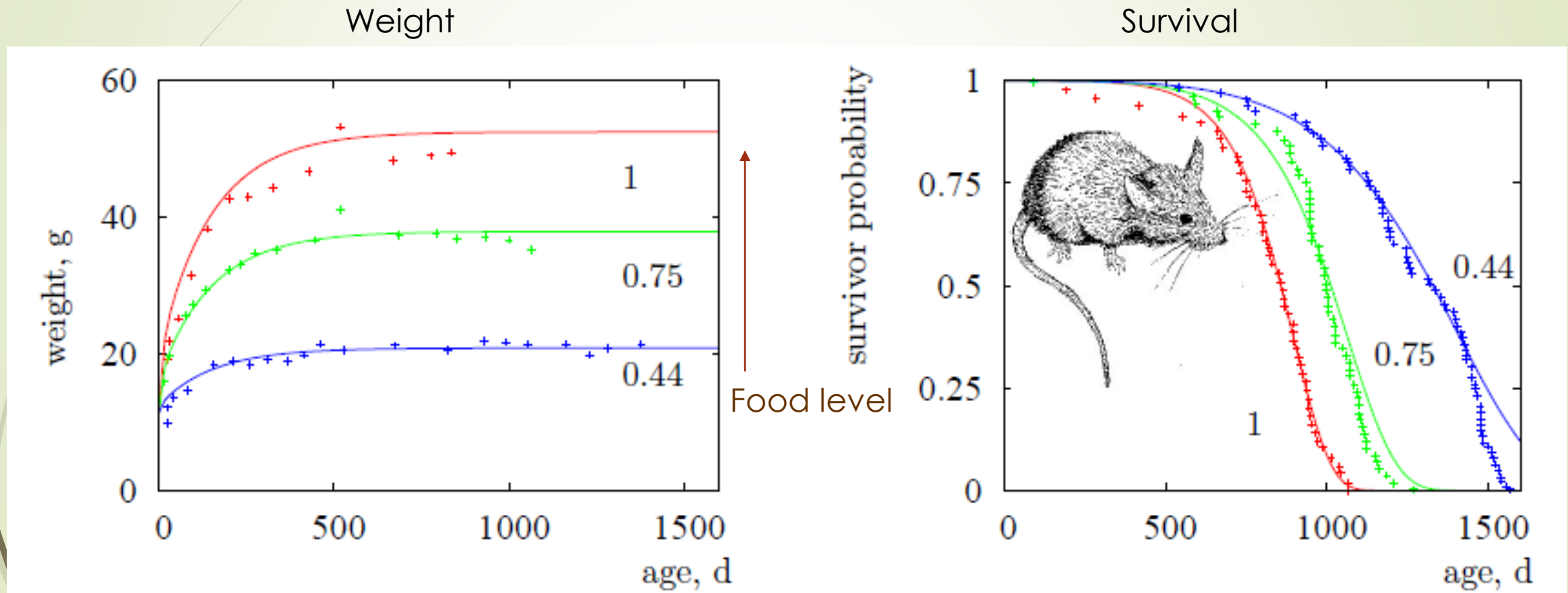


Ingestion flux

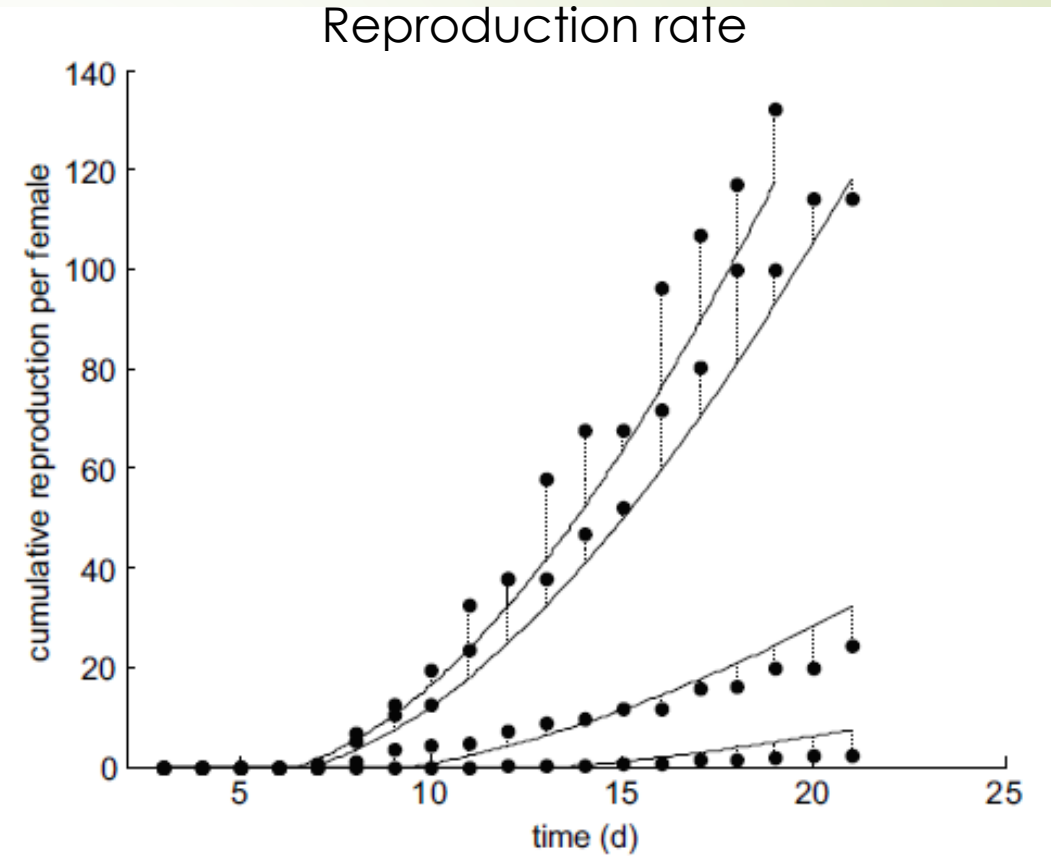
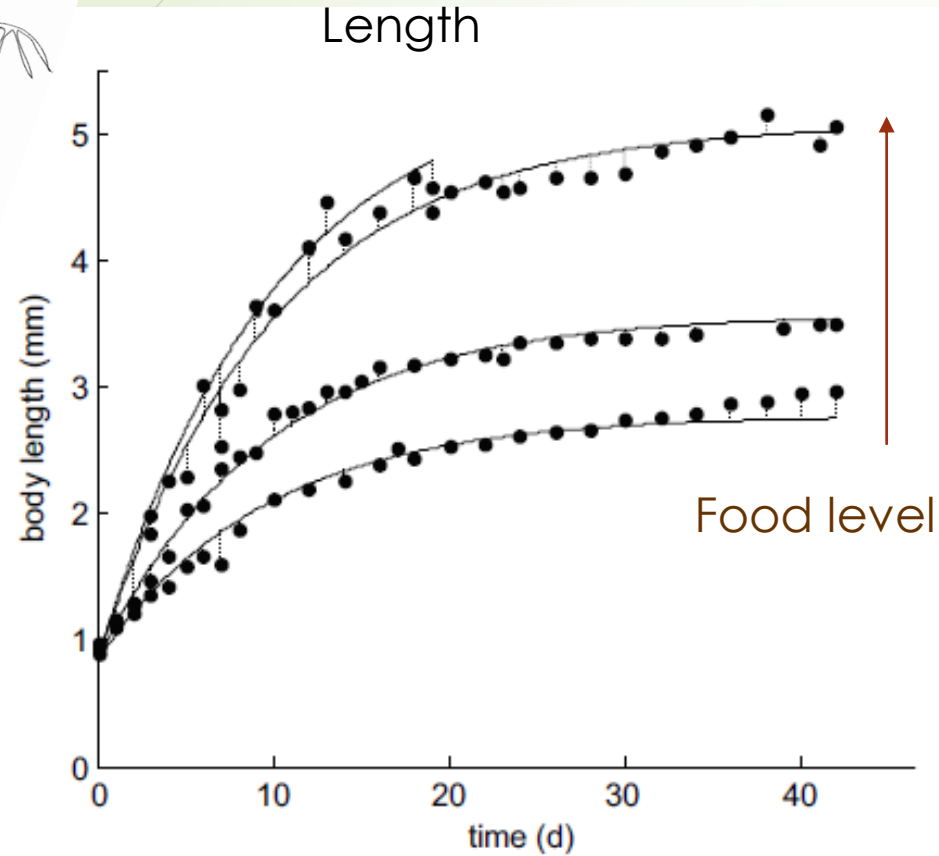
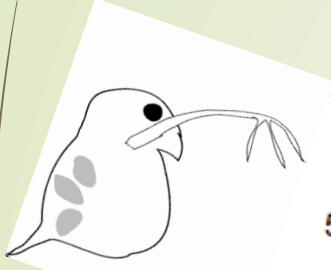
$$\dot{p}_X = f \dot{p}_{X_m} = f \{ \dot{p}_{X_m} \} L^2 \quad \text{with } f = \frac{x}{1+x}$$

Holling type II functional response

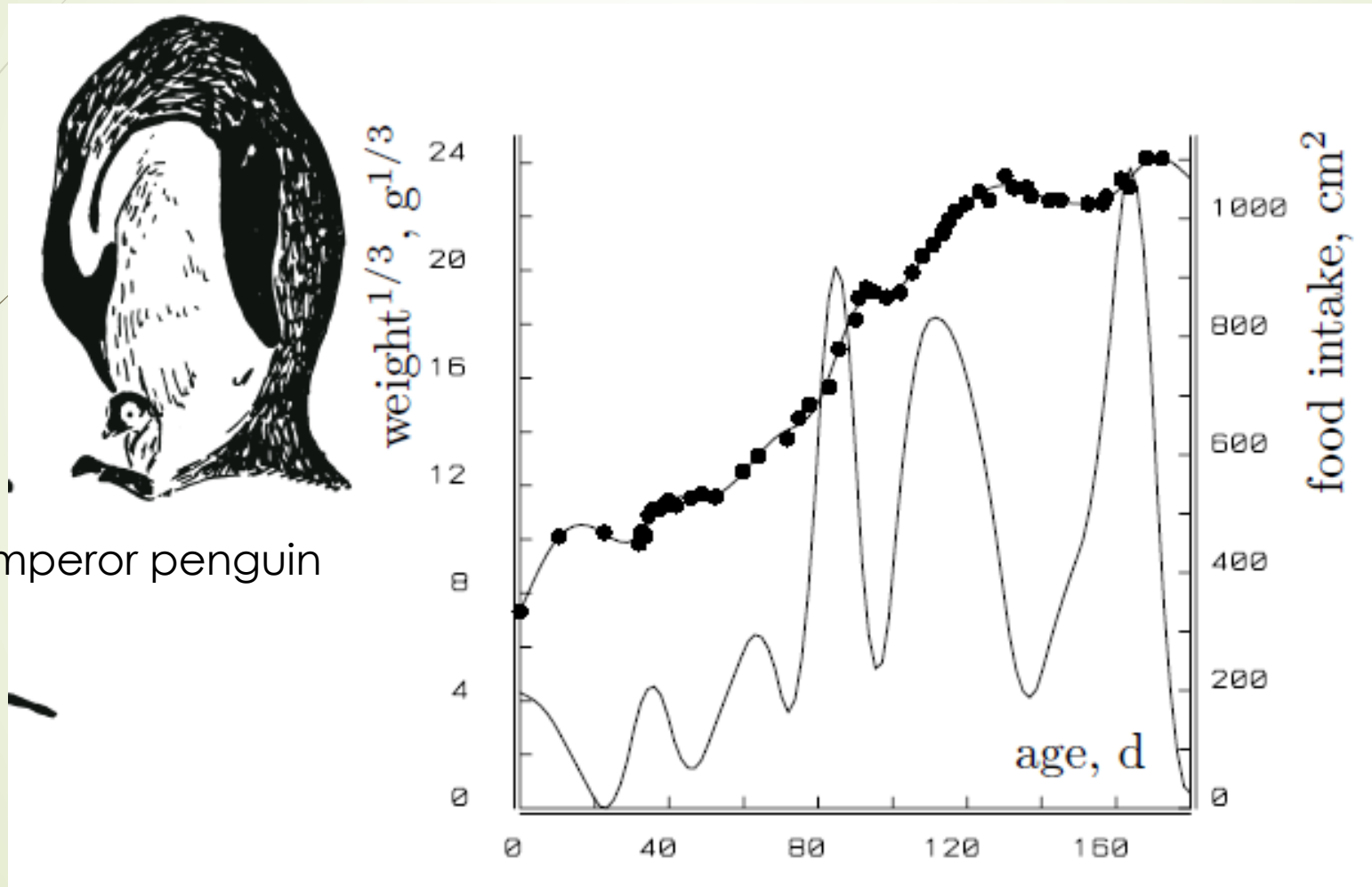
From Food to growth, aging, reproduction....



From Food to growth, aging, reproduction....

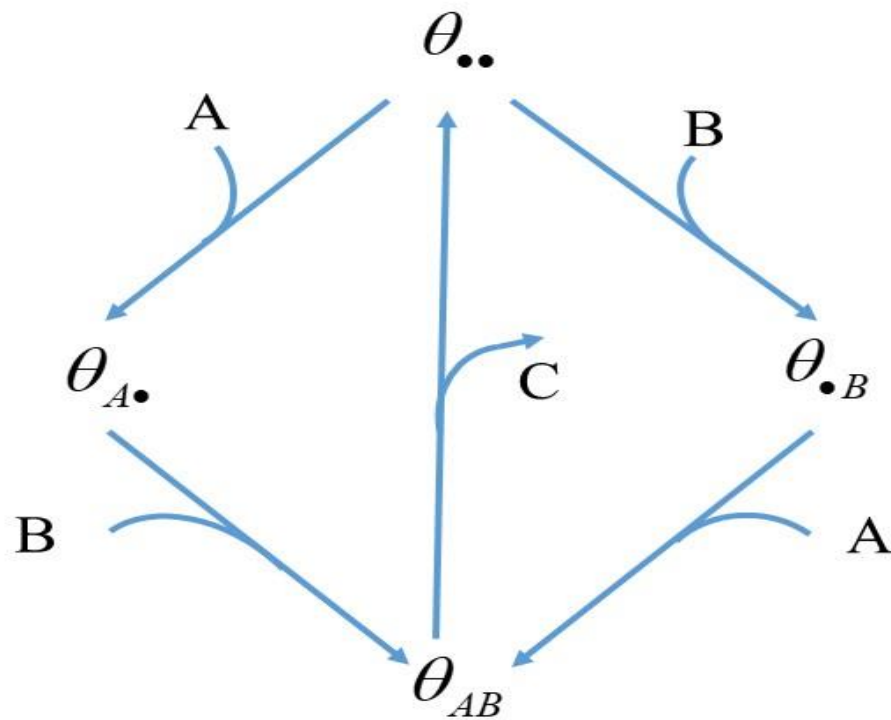


Food reconstruction



Synthesizing Unit (SU) concept

- Generalizes Michaelis-Menten kinetics with two substrates



$$\frac{d\theta_{..}}{dt} = -j_A\theta_{..} - j_B\theta_{..} + j_m\theta_{AB} = 0$$

$$\frac{d\theta_{A\cdot}}{dt} = j_A\theta_{..} - j_B\theta_{A\cdot} = 0$$

$$\frac{d\theta_{\cdot B}}{dt} = j_B\theta_{..} - j_A\theta_{\cdot B} = 0$$

$$\frac{d\theta_{AB}}{dt} = j_B\theta_{A\cdot} + j_A\theta_{\cdot B} - j_m\theta_{AB} = 0$$

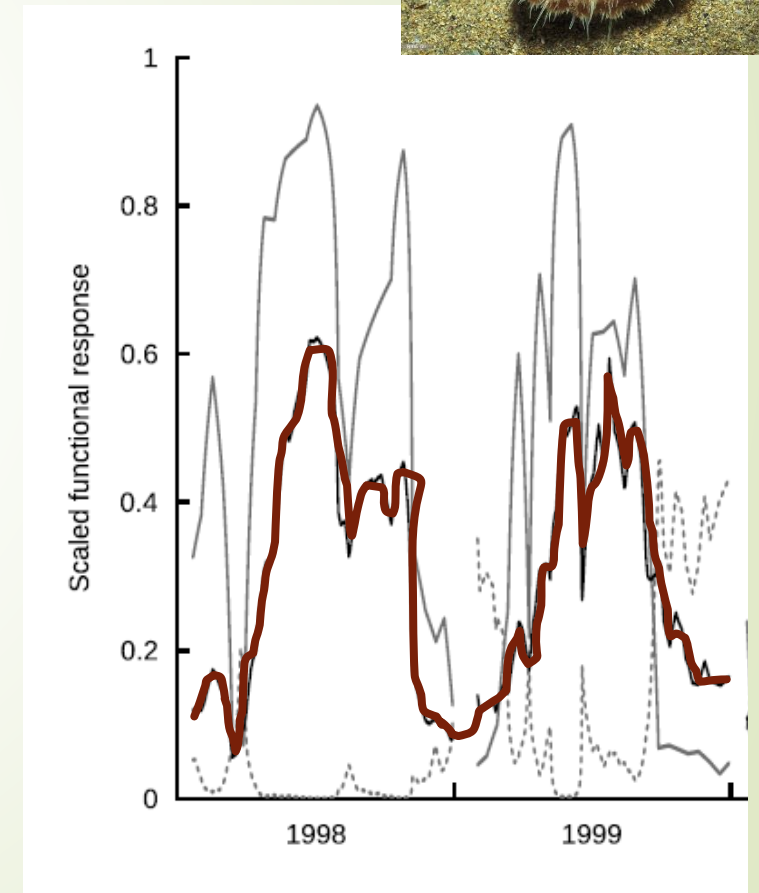
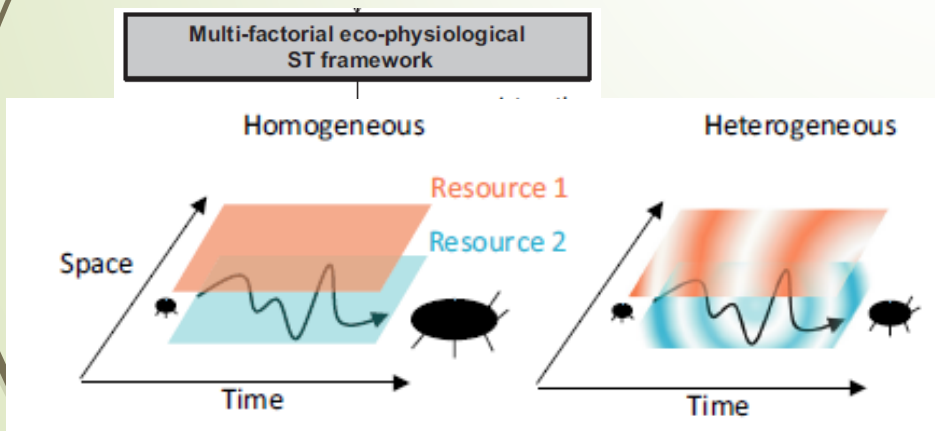
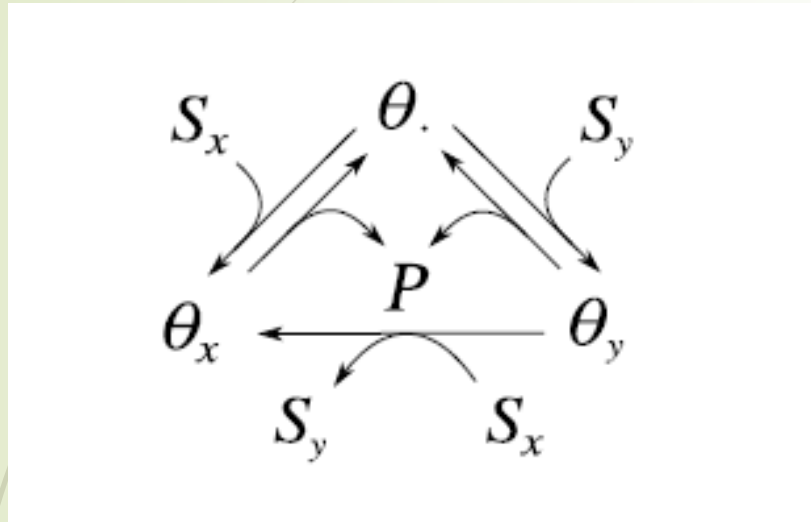
with $\theta_{..} + \theta_{A\cdot} + \theta_{\cdot B} + \theta_{AB} = 1$

implying

$$j_C = j_m\theta_{AB} = \frac{1}{j_m^{-1} + j_A^{-1} + j_B^{-1} - (j_A + j_B)^{-1}}$$

Synthesizing units: two substitutable food sources

➤ Microalgae or detritus for Great scallop



Lavaud et al., 2014



DEB and stoichiometry

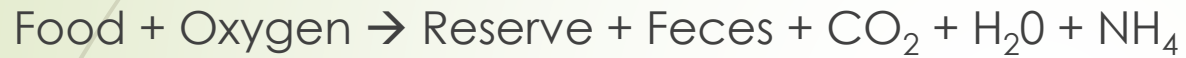
Mass balance using general compounds

	Organic compounds	Elemental composition	Mineral compounds
Food	X	$CH_{nX}O_{nX}N_{nX}$	C
Reserve	E	$CH_{nE}O_{nE}N_{nE}$	H
Structure	V	$CH_{nV}O_{nV}N_{nV}$	O
Feces	F	$CH_{nP}O_{nP}N_{nP}$	N ammonia NH_3 , urea $CO(NH_2)_2$, uric acid $C_5H_4O_3N_4$

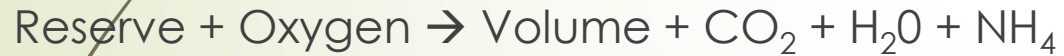
Macrochemical reactions

For mass balance purposes, only 3 macrochemical reactions with balanced stoichiometry

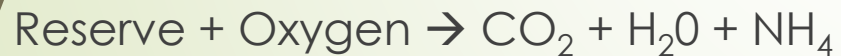
- ▶ Assimilation



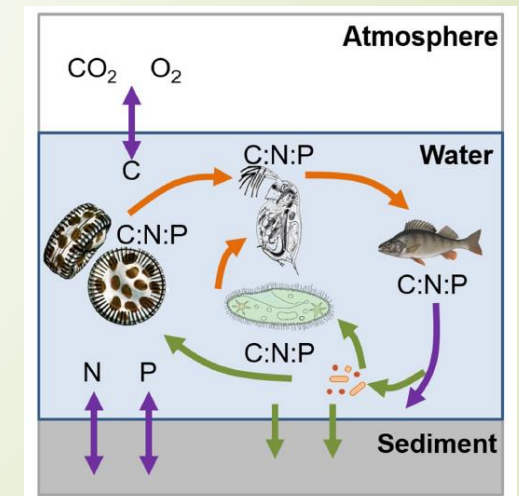
- ▶ Growth



- ▶ Dissipation

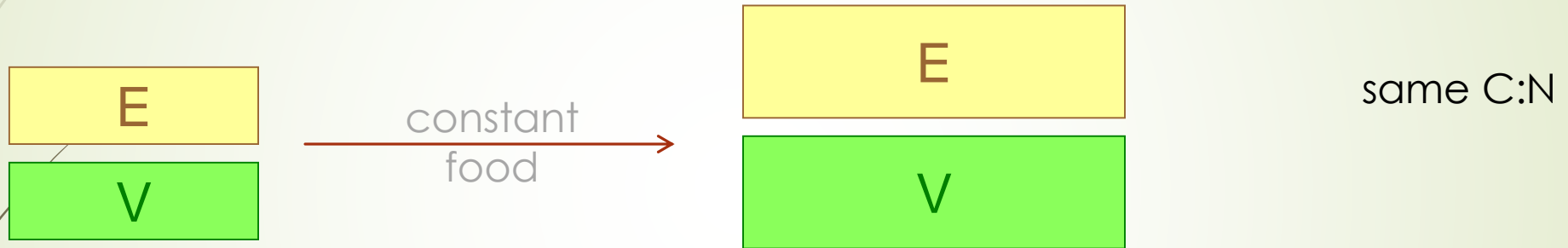


Ecological stoichiometry

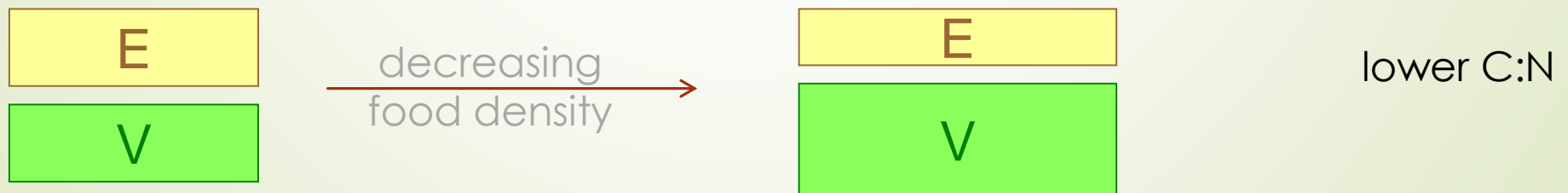


Change in elemental composition

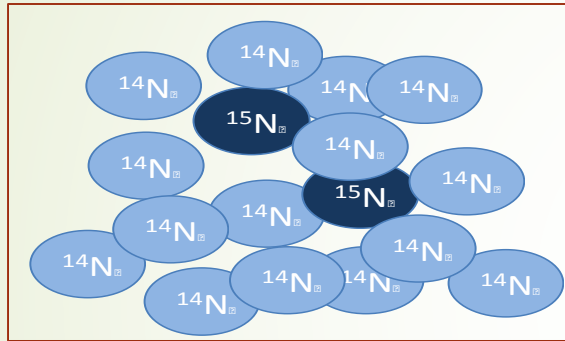
- ▶ In constant food density, the organism has a constant elemental composition (“**weak homeostasis**” assumption)



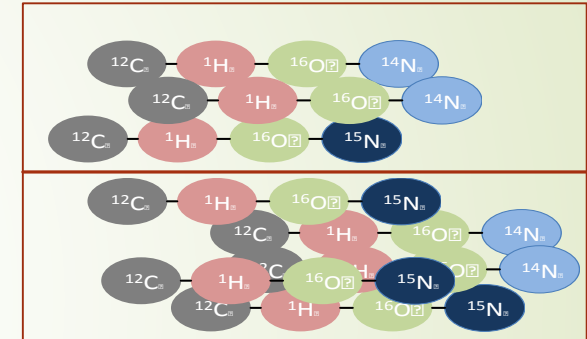
- ▶ In changing food environment, elemental composition (e.g. C:N) can change (the ratio E / V is changing and E and V have different chemical compositions)



DEB and Stable isotope dynamics



Classical simplification: organism =
“bag” of N atoms



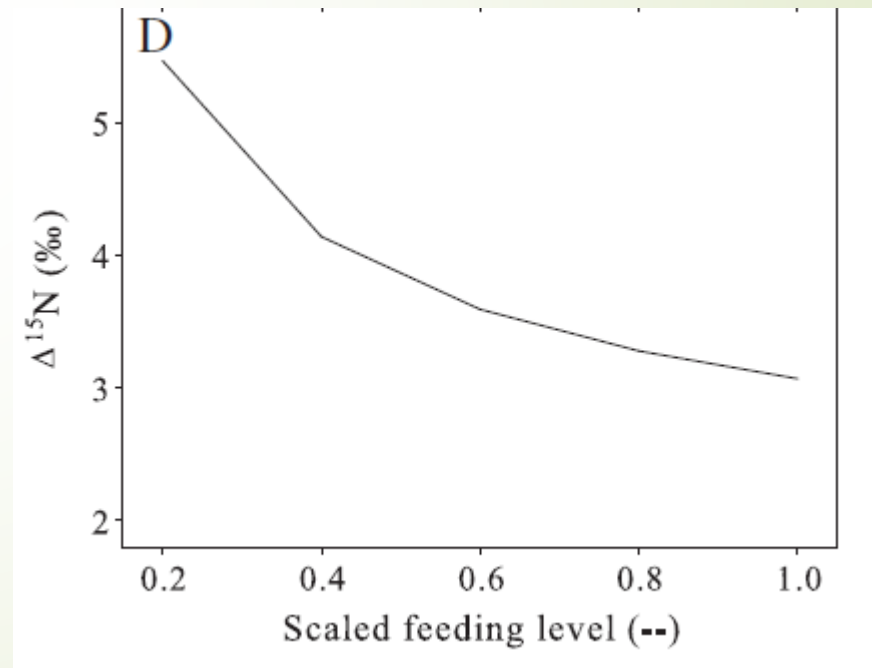
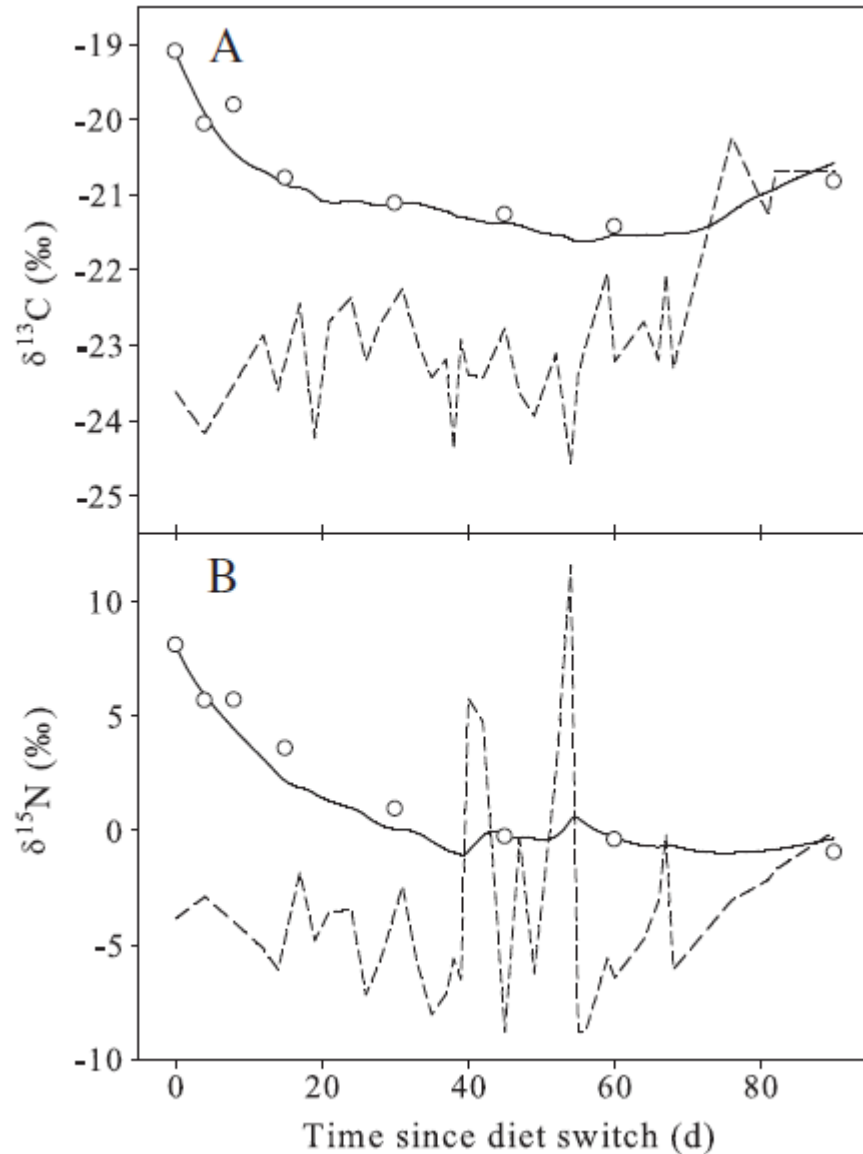
DEB representation: organism = sum
of two generalized compounds
containing light and heavy isotopes

Two new concepts within DEB framework: **Molecule reshuffling**, **Molecule selection** based
on bond strength

DEB and Stable isotope dynamics



- Classical diet switch experiment
- Impact of metabolism on discrimination

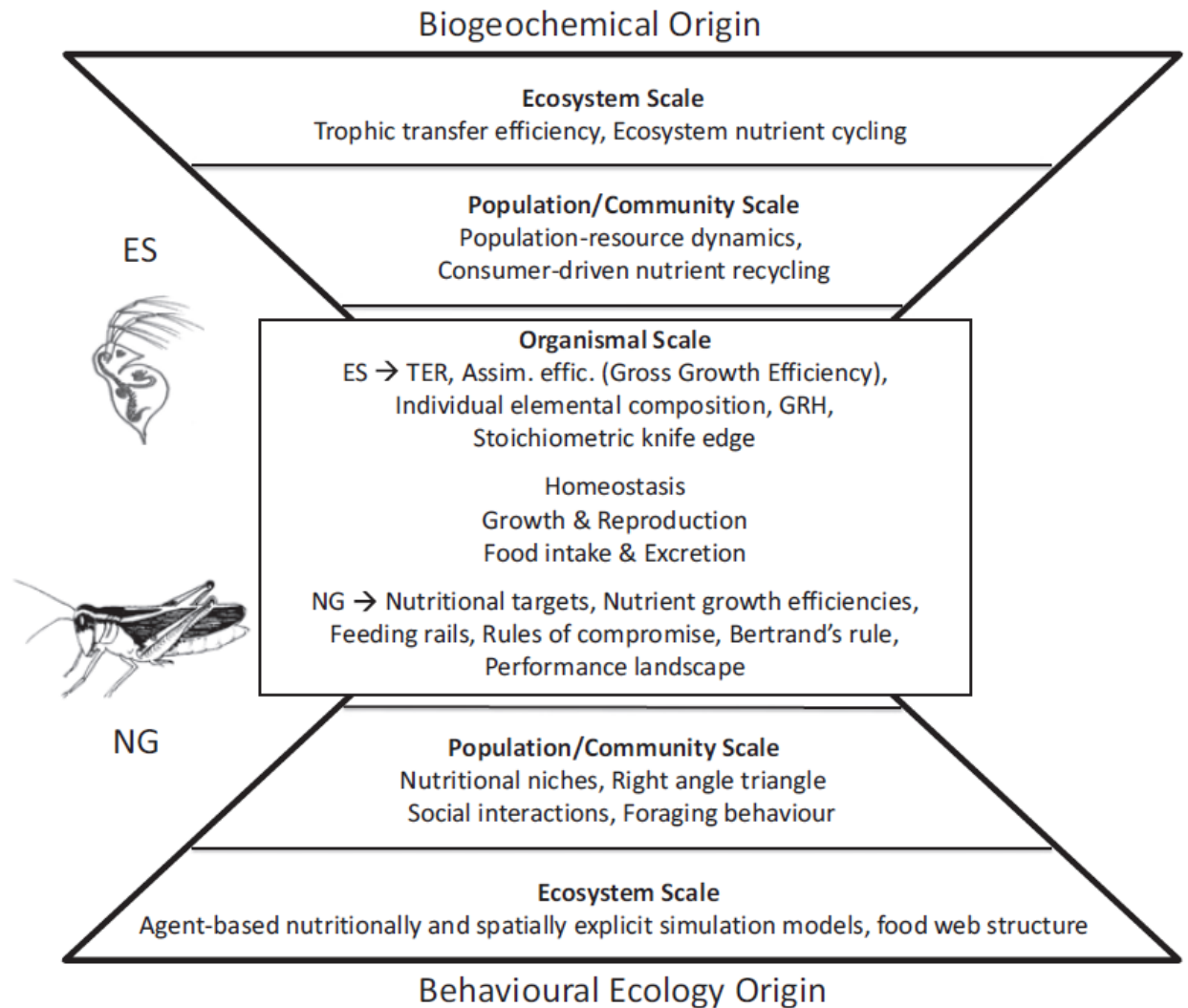




DEB and NG and ES

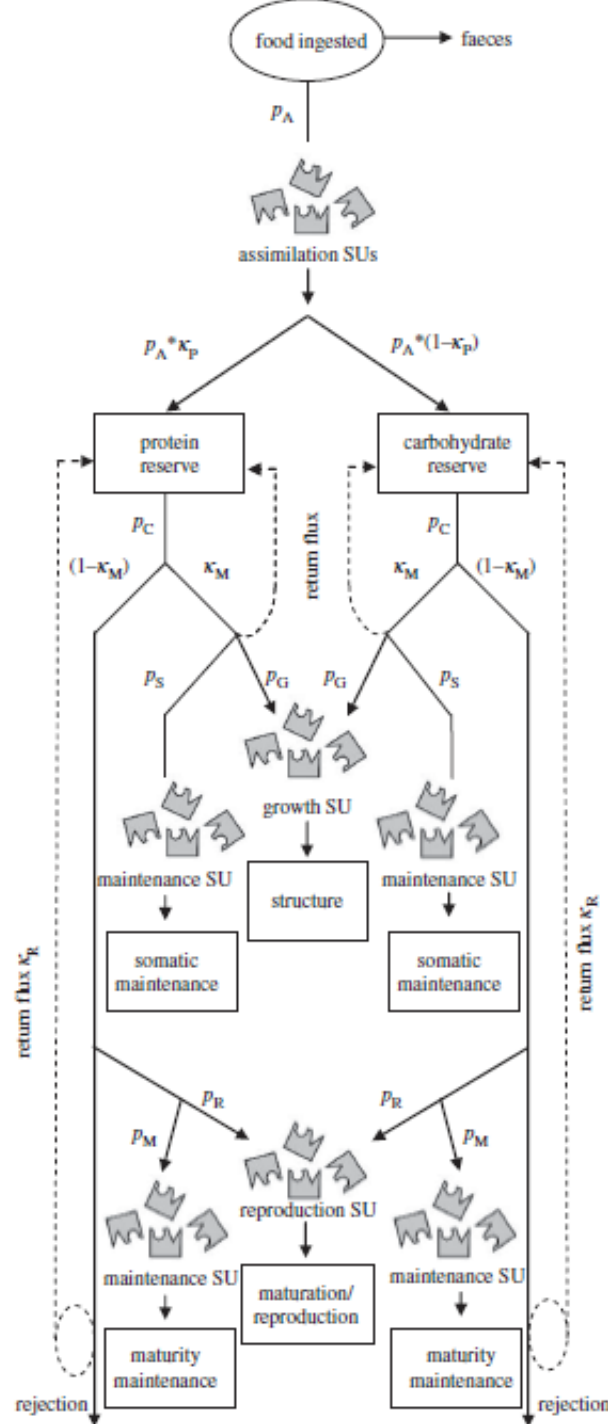
DEB bridges the gap between ES and NG

- Homeostasis concept
- General compounds are an intermediate “currency” between a **nutrient** currency (proteins/ carbohydrates/lipids, NG framework) and an **elemental** currency (C, N, P; ES framework)
- Development of two-reserves DEB model:
 - To cope with NG
 - To increase the plasticity of DEB stoichiometry for ES

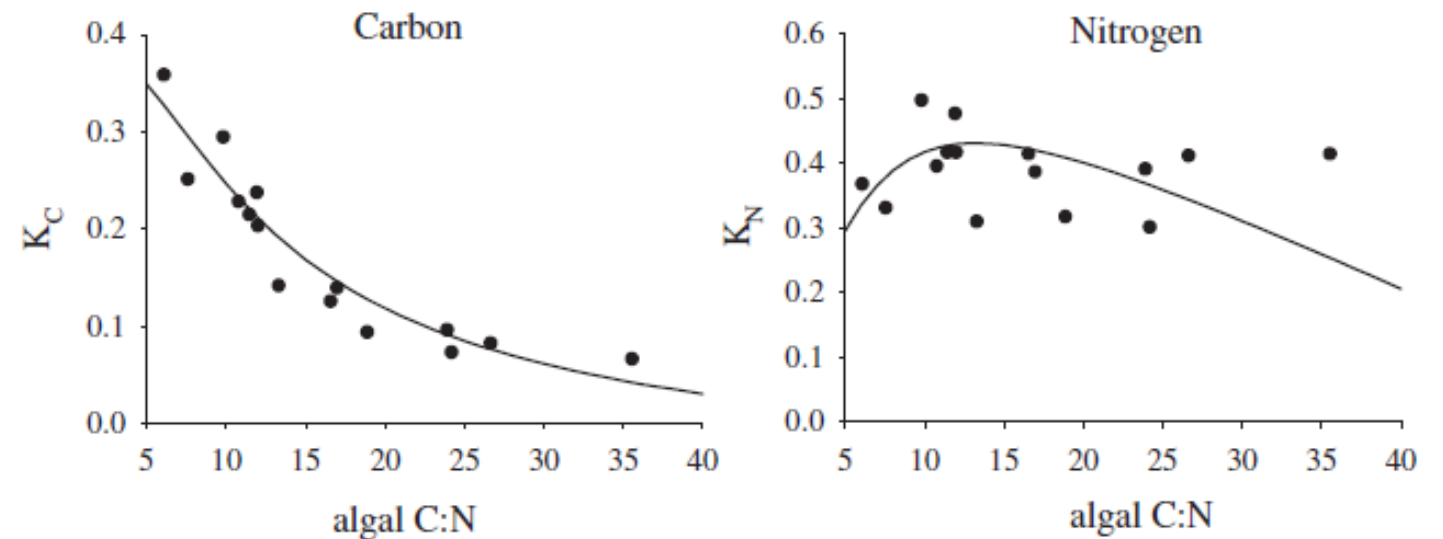


DEB extension: Two reserves, one structure & SUs

- Captures the general 'stylised empirical fact' that young (fast growing) individuals prefer protein-rich food types, while fully-grown individuals tend to prefer food types with less protein

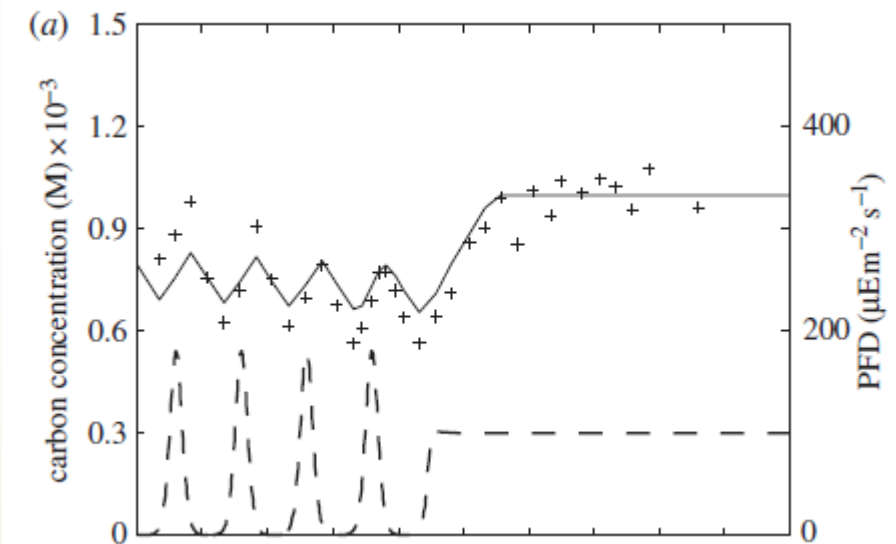
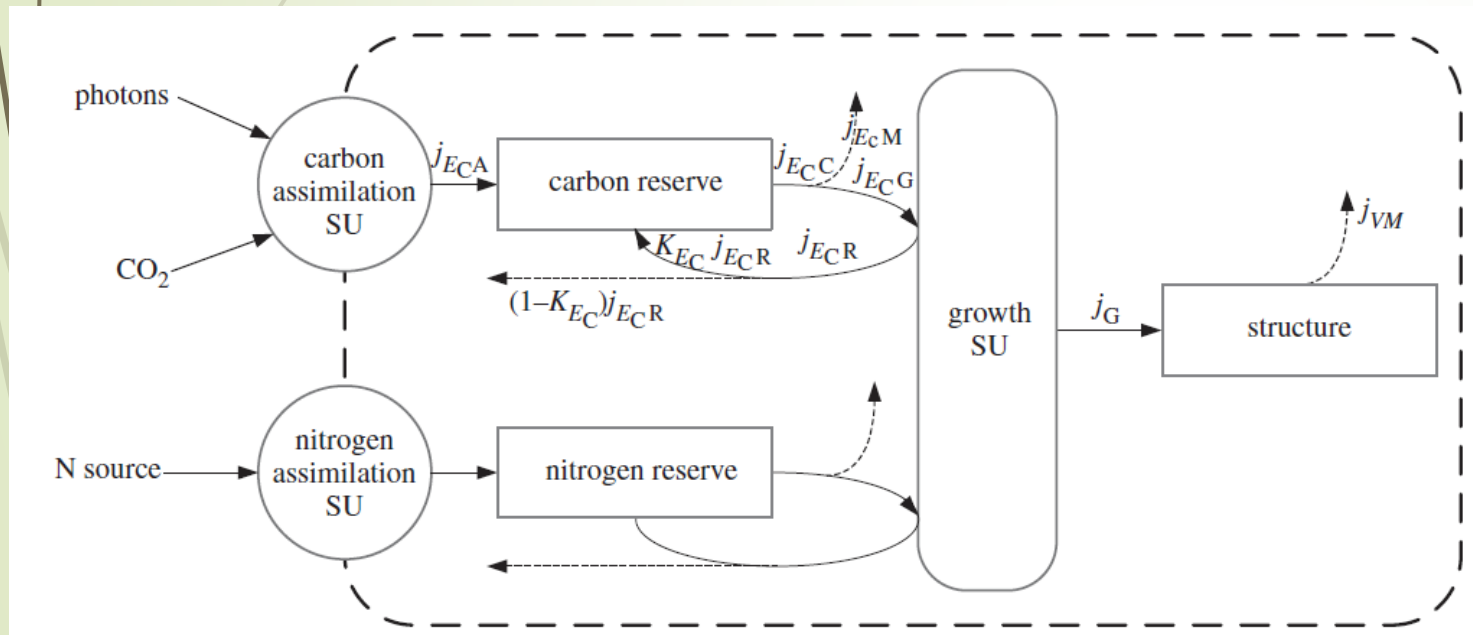
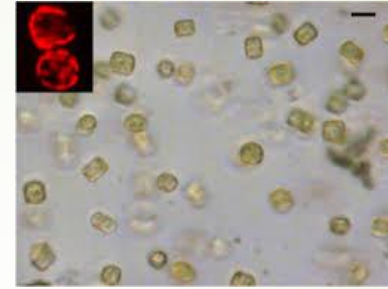


Gross growth



DEB extension: Two reserves, one structure & SUs

- Microalgae (*Thalassosira weissflogii*)





Scaling-up DEB to population and community

Individual to population models

Methods in Ecology and Evolution



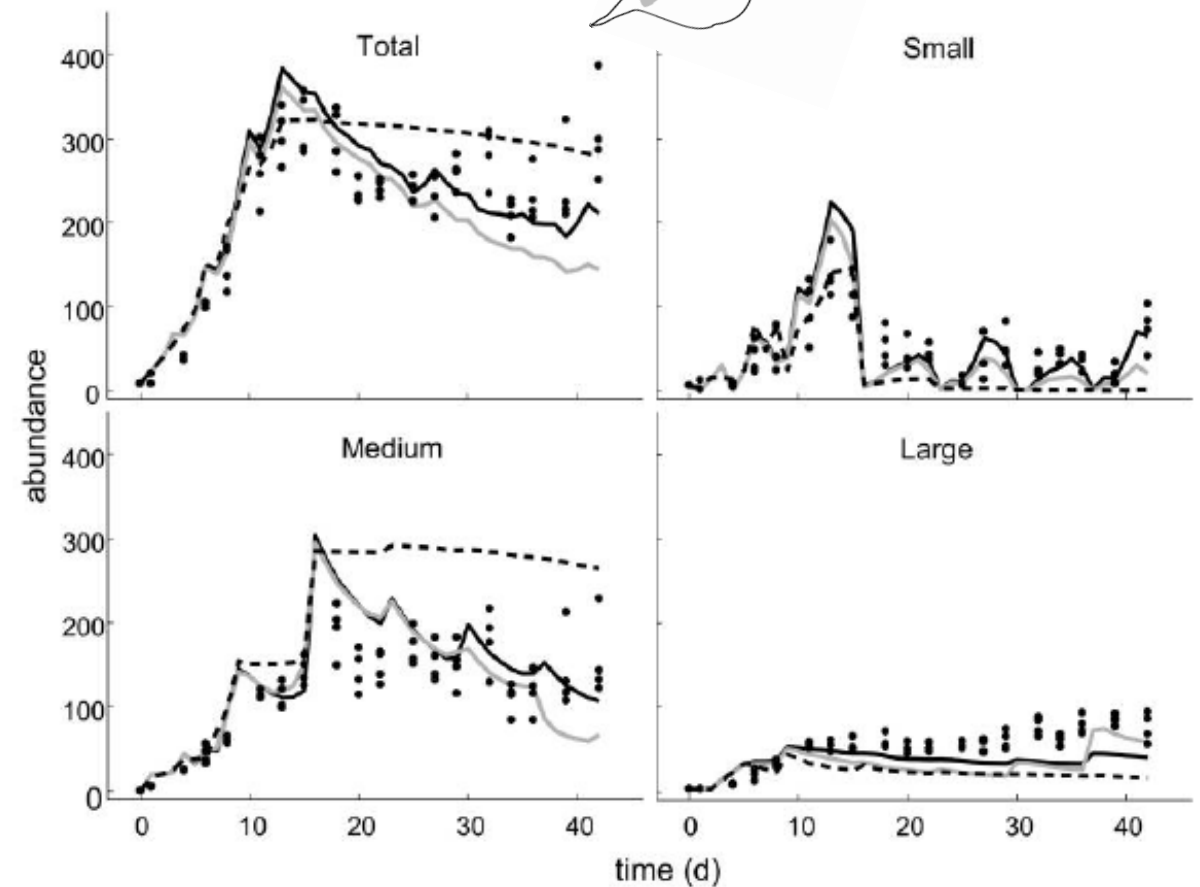
Methods in Ecology and Evolution 2012, 3, 445–449

doi: 10.1111/j.2041-210X.2011.00168.x

APPLICATION

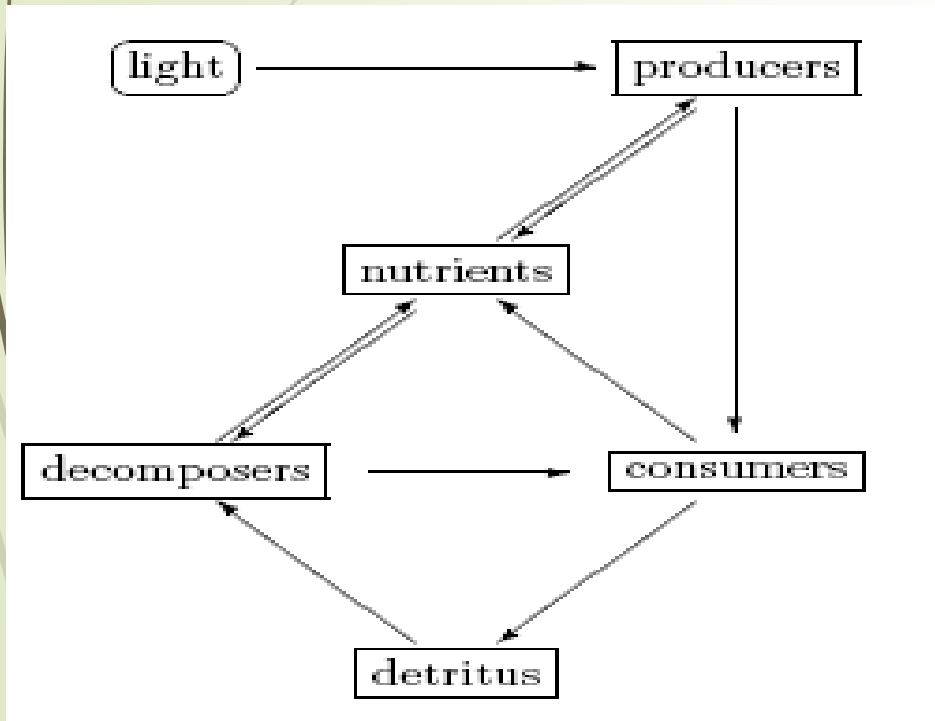
Dynamic Energy Budget theory meets individual-based modelling: a generic and accessible implementation

Benjamin T. Martin^{1*}, Elke I. Zimmer², Volker Grimm¹ and Tjalling Jager²

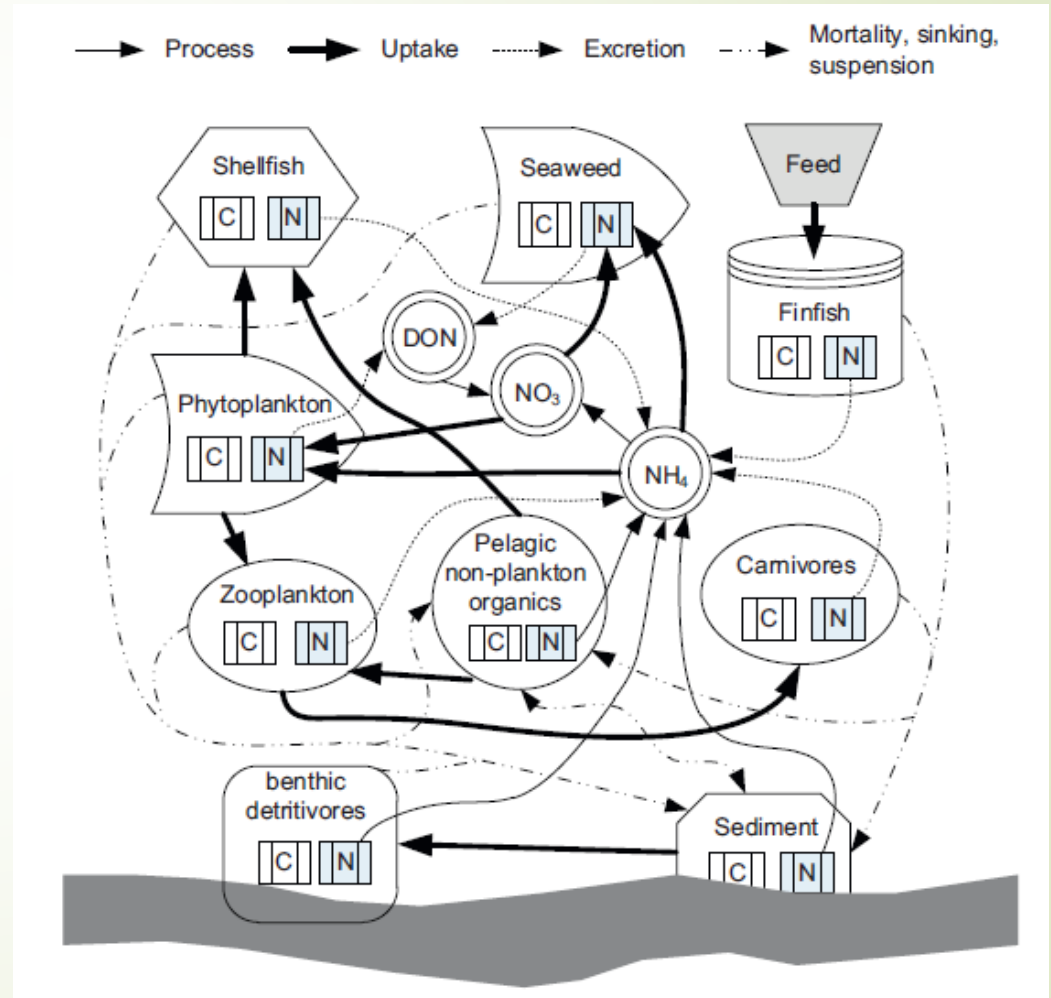


DEB in Ecosystem Models

Prototype model: "Canonical community"
(Kooijman 2010, chapter 9)



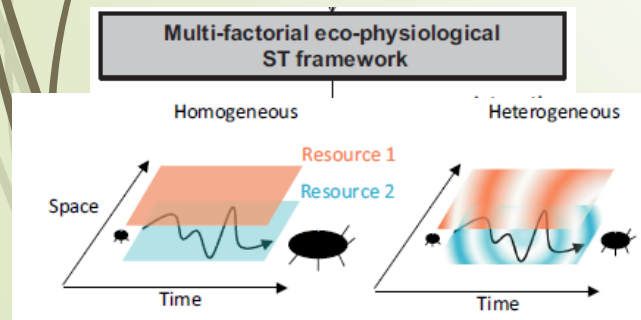
Ren et al., 2012



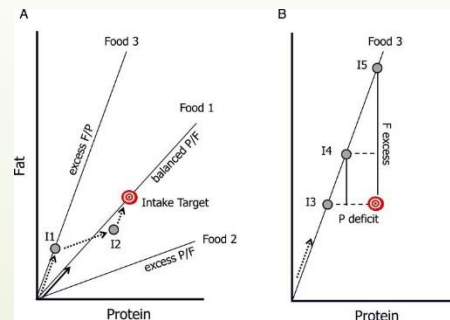
See also adaptation for ERSEM Marques et al., 2015

Take home messages

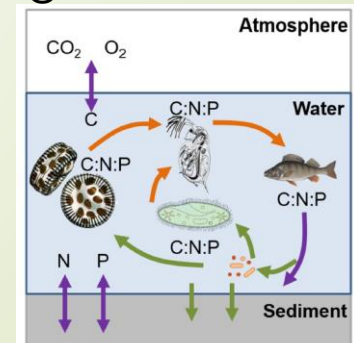
- DEB is a theory with a suite of models and extensions
- Mostly developed at the organism scale
- Applications at population or ecosystem scale are still under developed
- Dedicated to dynamic environment and with several resources (SUs):
fit with multi-factorial scale theory?
- The existing framework can integrate concepts of Ecological stoichiometry and nutritional geometry but remains challenging (model structure, data availability)
- We need a task to fully exploit the theory in the context of trophic ecology



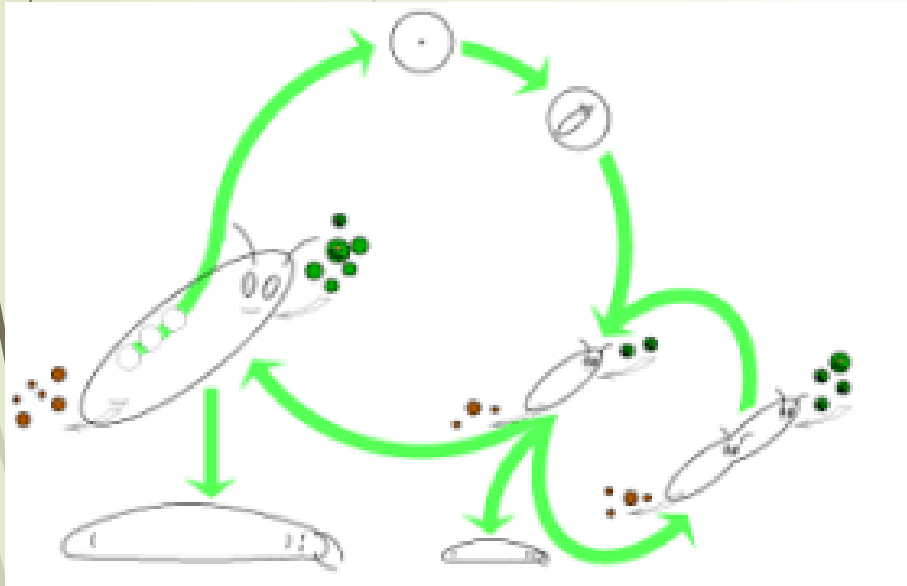
Nutritional geometry



Ecological stoichiometry



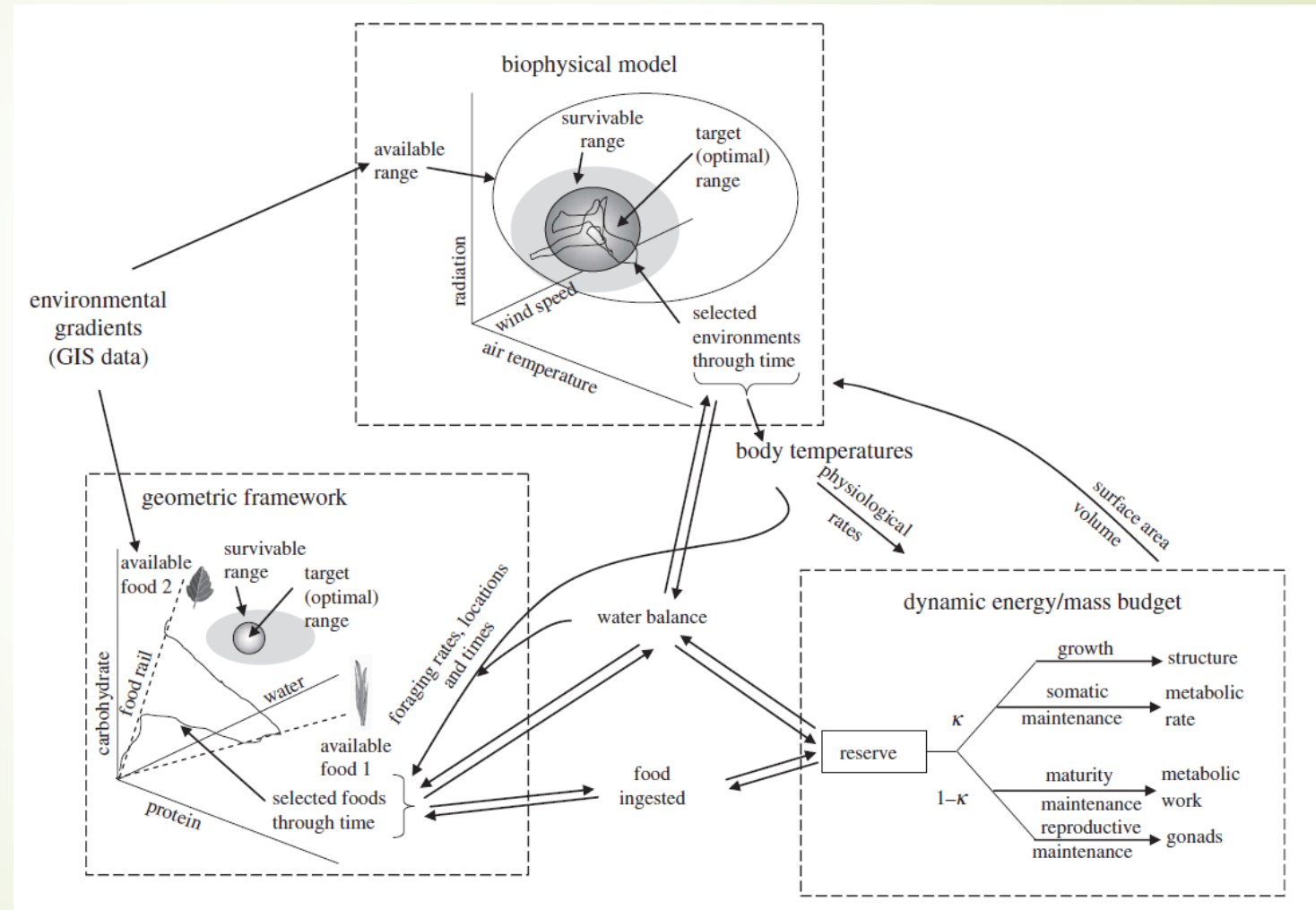
Thanks for your attention



- ▶ AmP Portal
http://www.bio.vu.nl/thb/deb/deblab/add_my_pet/index.html
- ▶ DEB Wiki
www.debtheory.org/wiki
- ▶ DEB Matlab routines on Github
<https://github.com/add-my-pet>
- ▶ DEB library on Zotero
www.zotero.org/groups/500643/deb_library
- ▶ DEB mailing list
deb@listes.univ-brest.fr; 130 subscribers
- ▶ DEBnet
www.debtheory.org/wiki/index.php?title=DEBnet
- ▶ AmP Project pages on Facebook and Researchgate

DEB provides life history traits

- Functional approach
- Traits
- (trophic) Niche



Kooijman's "Standard" DEB model equations

$$\frac{d}{dt}M_E = \dot{J}_{EA} - \dot{J}_{EC}$$

$$\frac{d}{dt}M_V = \dot{J}_{VG} = (\kappa \dot{J}_{EC} - \dot{J}_{EM}) y_{VE}$$

$$\frac{d}{dt}M_H = (1 - \kappa) \dot{J}_{EC} - \dot{J}_{EJ} \quad \text{if } M_H < M_H^p, \text{ else } \frac{d}{dt}M_H = 0$$

$$\frac{d}{dt}M_{ER} = 0 \quad \text{if } M_H < M_H^p, \text{ else } \frac{d}{dt}M_{ER} = (1 - \kappa) \dot{J}_{EC} - \dot{J}_{EJ}$$

$$\text{with } \dot{J}_{EA} = c(T) f\{\dot{J}_{EAm}\} L^2 \quad \text{if } M_H \geq M_H^b \text{ else } \dot{J}_{EA} = 0$$

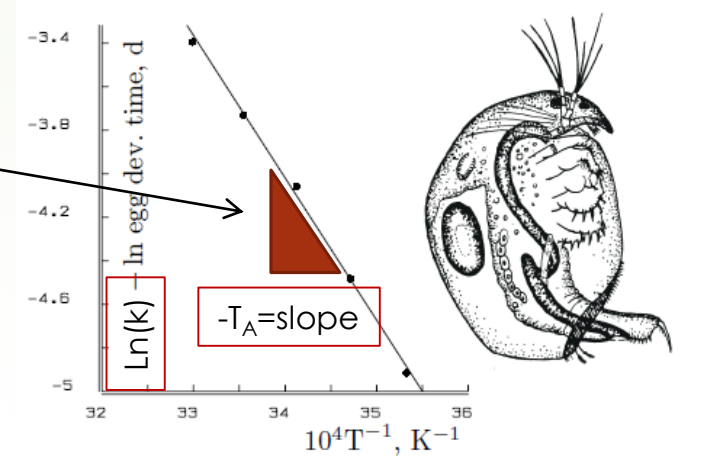
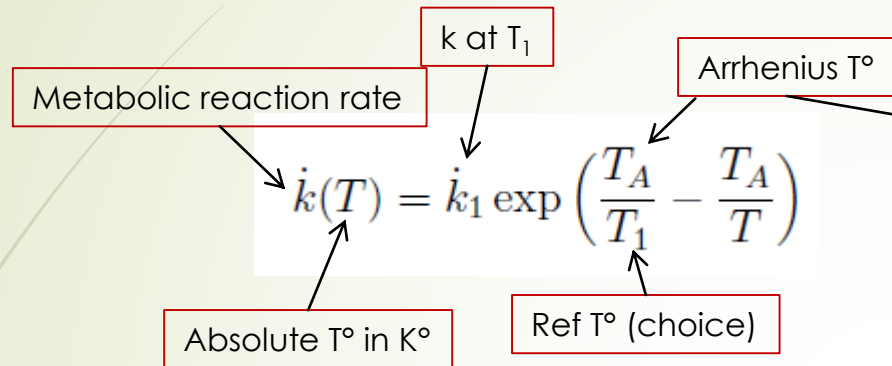
$$\dot{J}_{EC} = c(T) \{\dot{J}_{EAm}\} L^2 \frac{ge}{g+e} \left(1 + \frac{L}{gL_m}\right)$$

$$\dot{J}_{EM} = c(T) [\dot{J}_{EM}] L^3$$

$$\dot{J}_{EJ} = c(T) \dot{k}_J M_H$$

PLUS ODEs for aging acceleration and hazard rates

Temperature effect on processes



$$\dot{k}(T) = \dot{k}_1 \exp\left(\frac{T_A}{T_1} - \frac{T_A}{T}\right) \left(1 + \exp\left(\frac{T_{AL}}{T} - \frac{T_{AL}}{T_L}\right) + \exp\left(\frac{T_{AH}}{T} - \frac{T_{AH}}{T}\right)\right)^{-1} \quad (1.3)$$

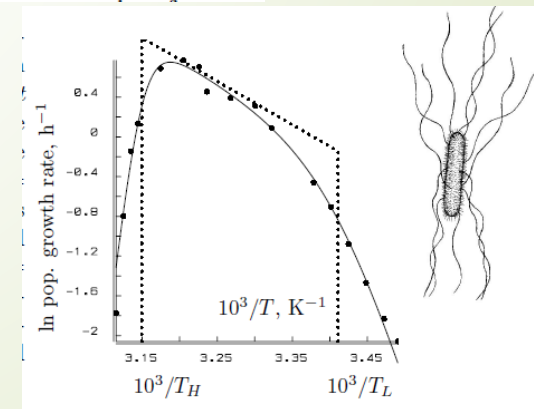
where T_L and T_H relate to the lower and upper boundaries of the tolerance range and T_{AL} and T_{AH} are the Arrhenius temperatures for the rate of decrease at both boundaries. All are taken to be positive and all have dimension temperature. We usually find $T_{AH} \gg T_{AL}$.

Changing the rate for a given ref T° (in K°)

$$\dot{r}_B(T_2) = \dot{r}_B(T_1) \exp(T_A(T_1^{-1} - T_2^{-1}))$$

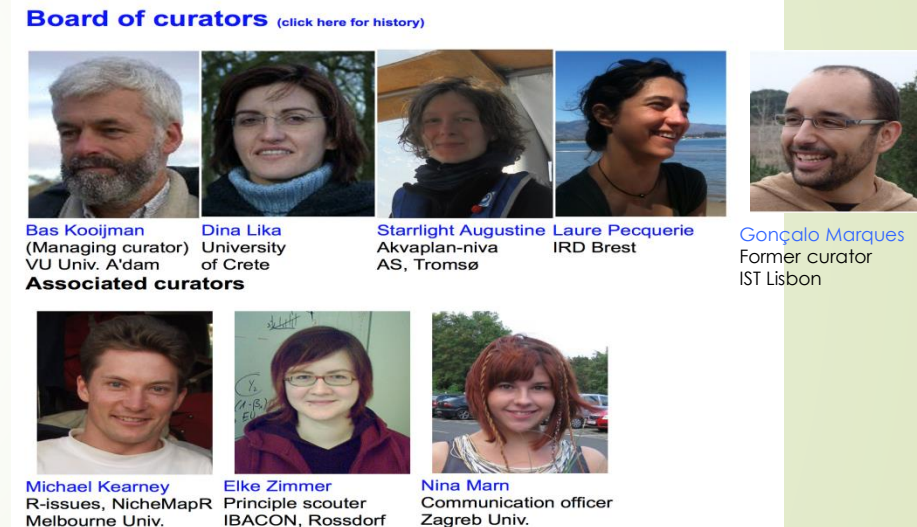
Which rates are affected? For example:

$$\{\dot{F}_m\}, \{\dot{J}_{EAm}\}, \dot{v}, \{\dot{J}_{ET}\}, [\dot{J}_{EM}], \dot{k}_j$$



DEB parameter estimation: the AmP project

- ▶ 2009: AmP (Add-my-Pet) project: Comparing **animal** species on the basis of DEB parameters (S.A.L.M. Kooijman)
- Each AmP entry:
 1. Referenced data on the energetics of an animal species
 2. Matlab Code for estimating DEB parameters from these data
 3. DEB parameter estimates
 4. Properties of the species/population/individual that are implied by these parameters



Sept 2018:

1273 species, 125 authors

All large phyla, all chordate orders

A range of 16 order of magnitude in body mass

Macrochemical reactions

36

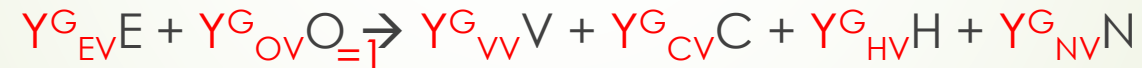
Y_{EX}^A = number of C-moles of E per C-moles of X

- For mass balance purposes, only 3 macrochemical reactions

- Assimilation



- Growth



- Dissipation



=1

=1