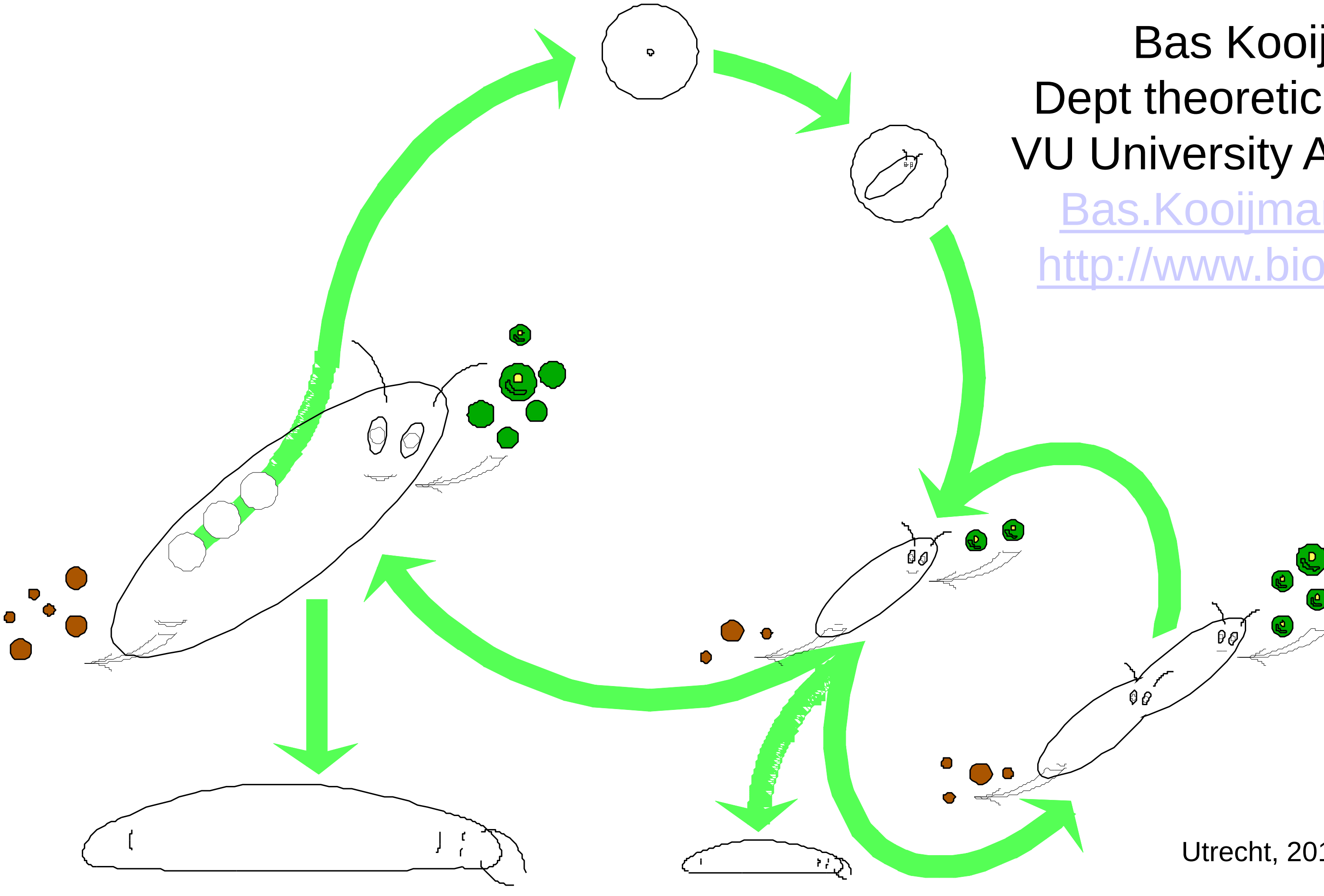
Dynamic Energy Budget theory: where fascination meets profession



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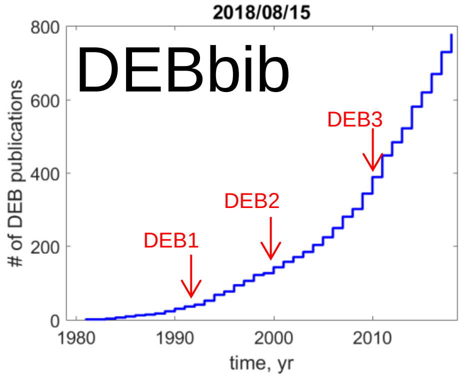
Utrecht, 2015/08/26/12:00

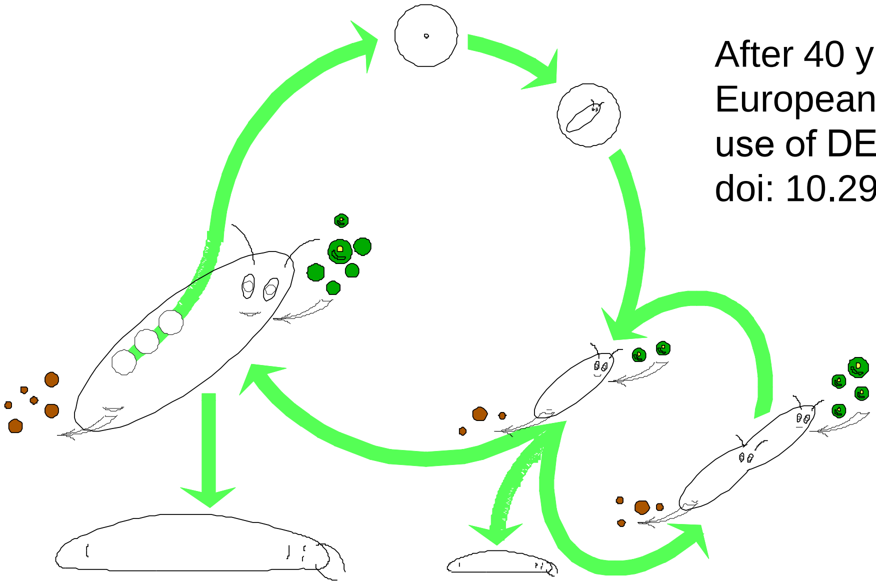
Dynamic Energy Budget

Start: Aug 1979 understanding effects of toxicants
Now: bibliography of 785 DEB papers:
https://www.zotero.org/groups/500643/deb_library/



Dynamic:
- Full life cycle (embryo, juvenile, adult) in changing environment (temp, food)

Energy:
- Feeding
- Digestion
- Storing
- Growth
- Maturation
- Maintenance
- Reproduction
- Product formation
- Aging



After 40 yrs of work: 27 June 2018
European Food Safety Authority:
use of DEB's for risk assessment
doi: 10.2903/j.efsa.2018.5377

Budget:
- Conservation: energy, mass, time, isotopes

Concepts

- Metabolic rate

  O2 consumption, CO2 or heat production? Entropy dissipation!

  metabolic rate does not explain everything!

  reproduction hardly depends on instantaneous metabolic rate

- Body size

  not an independent variable, but results from processes

  reserve, reproduction buffer complicate interpretation of mass

Conclusions

not scaling but co-variation of parameter values

allometry involves interpretation problems, $\Delta O_2 = \sum_i \; f_i \,(W) \neq a\, W^b$

distinguish between intra- and inter-specific comparisons

Homeostasis 1.2

strong homeostasis

constant composition of pools (reserves/structures)
generalized compounds, stoichiometric constraints on synthesis

weak homeostasis

constant composition of biomass during growth in constant environments
determines reserve dynamics (in combination with strong homeostasis)

structural homeostasis

constant relative proportions during growth in constant environments
isomorphy .work load allocation

thermal homeostasis

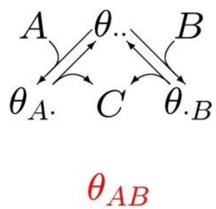
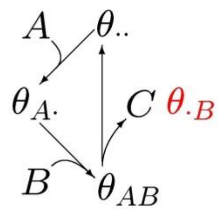
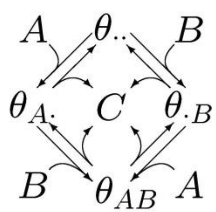
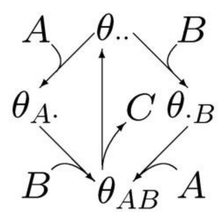
ectothermy → homeothermy → endothermy

acquisition homeostasis

supply → demand systems

development of sensors, behavioural adaptations

Interactions of substrates 3.7.3b

	substitutable $y_{CA}A \rightarrow C;\; y_{CB}B \rightarrow C$	complementary $y_{CA}A + y_{CB}B \rightarrow C$
sequential	 $j_C = \frac{j''_A + j''_B}{1 + j'_A/k_A + j'_B/k_B}$ $j_A^+ = \frac{j'_A}{1 + j'_A/k_A + j'_B/k_B}$	 $j_C = \frac{1}{k^{-1} + j''^{-1}_A + j''^{-1}_B}$ $j_A^+ = y_{AC}\, j_C$
parallel	 $j_C = \frac{y_{CA}}{k_A^{-1} + j'^{-1}_A} + \frac{y_{CB}}{k_B^{-1} + j'^{-1}_B}$ $j_A^+ = \frac{1}{k_A^{-1} + j'^{-1}_A}$	 $j_C = \frac{1}{k^{-1} + j''^{-1}_A + j''^{-1}_B - (j''_A + j''_B)^{-1}}$ $j_A^+ = y_{AC}\, j_C$

Synthesising Units

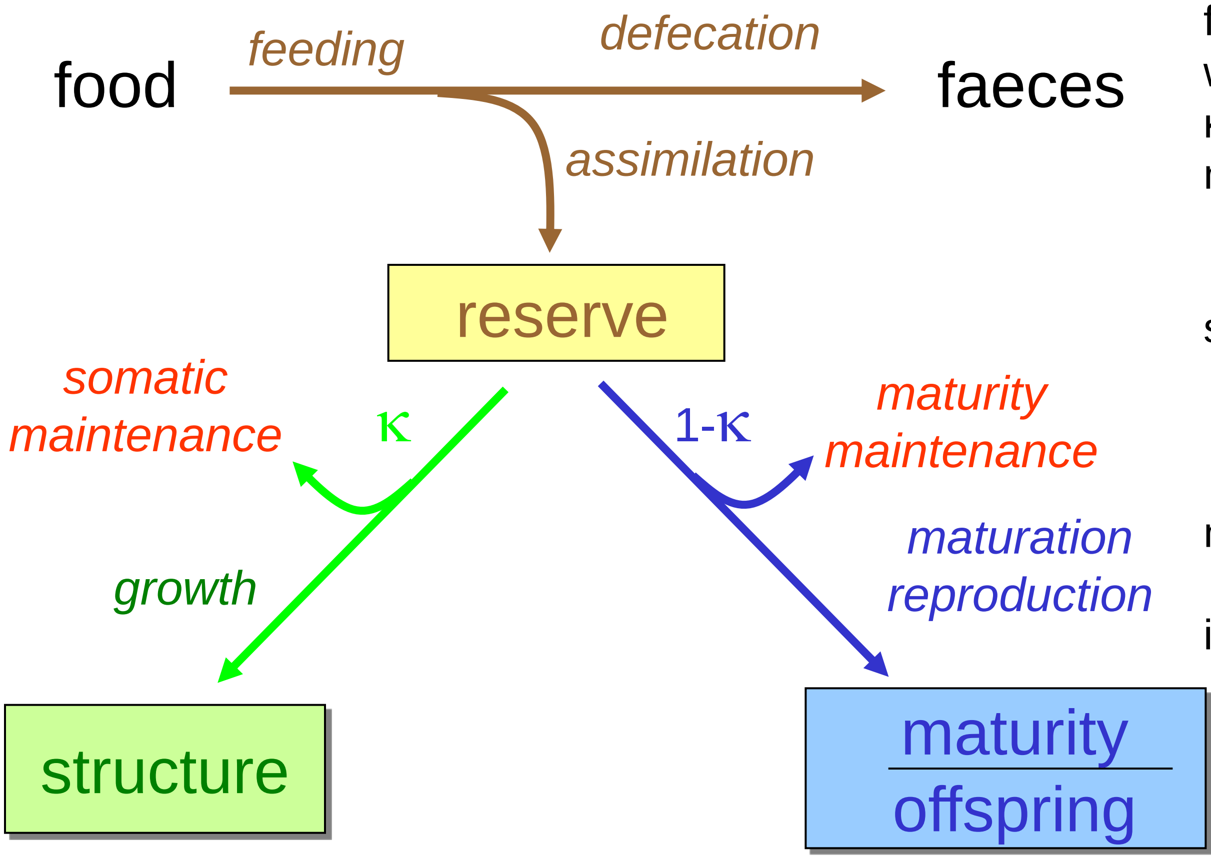
- SU = enzyme mol, individual
- on the basis of fluxes
- acctepted/ rejected fluxes
- no backward transformation
- free/busy states: feeding
- Markov process
- extended to
- inhibition,
- co-metabolism
- syntrophy
- social interactions

k_*	dissociation rate for $*$	j_*	spec. flux of compound $*$
j_*^+	spec. accepted flux	j_*^-	spec. rejected flux
j'_*	scaled flux: $\rho_* j_*$	j''_*	scaled flux: $y_{C*} j'_*$
ρ_*	binding probability	θ_*	fraction occupied by $*$

Kooijman, 2001
Phil Trans R Soc B
356: 331-349

Standard DEB scheme

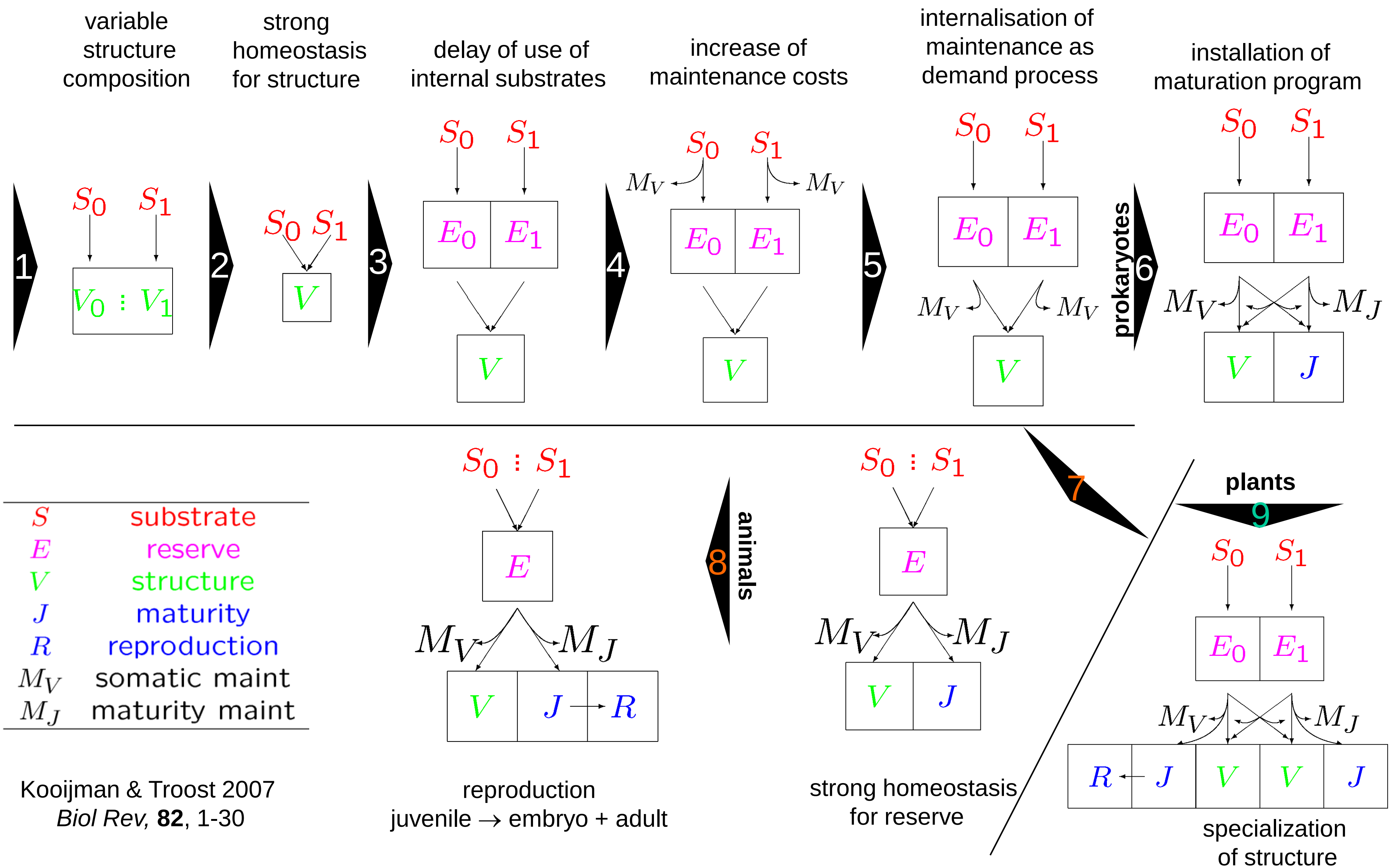
1 food type, 1 reserve, 1 structure, isomorph



time: searching & handling
feeding ∝ surface area
weak & strong homeostasis
κ-rule for allocation to soma
maintenance has priority
  somatic maint ∝ structure
  maturity maint ∝ maturity
stage transition: maturation
  embryo: no feeding, reprod
  juvenile: no reproduction
  adult: no maturation
maternal effect: reserve density
  at birth equals that of mother
initially: zero structure, maturity
  egg = blob of reserve

reproduction
  via reproduction buffer
  buffer handling rules

Evolution of DEB systems 10.3



S	substrate
E	reserve
V	structure
J	maturity
R	reproduction
M_V	somatic maint
M_J	maturity maint

Kooijman & Troost 2007
Biol Rev, **82**, 1-30

Evolution of DEB systems 10.3a

- Start: variable biomass composition, passive uptake
- Strong homeostasis → stoichiometric constraints
- Reserves: delay of use of internalised substrates → storage, weak homeostasis
- Maintenance requirements: turnover (e.g. active uptake by carriers), regulation
- Maintenance from reserve instead of substrate; increase reserve capacity
- Control of morphology via maturation; κ-rule ↔ cell cycle
- Diversification of assimilation (litho- → photo- → heterotrophy)

Eukaryotisation: heterotrophic start; unique event?

- Syntrophy & compartmentalisation: mitochondria, genome reorganisation
- Phagocytosis, plastids (acquisition of phototrophy)

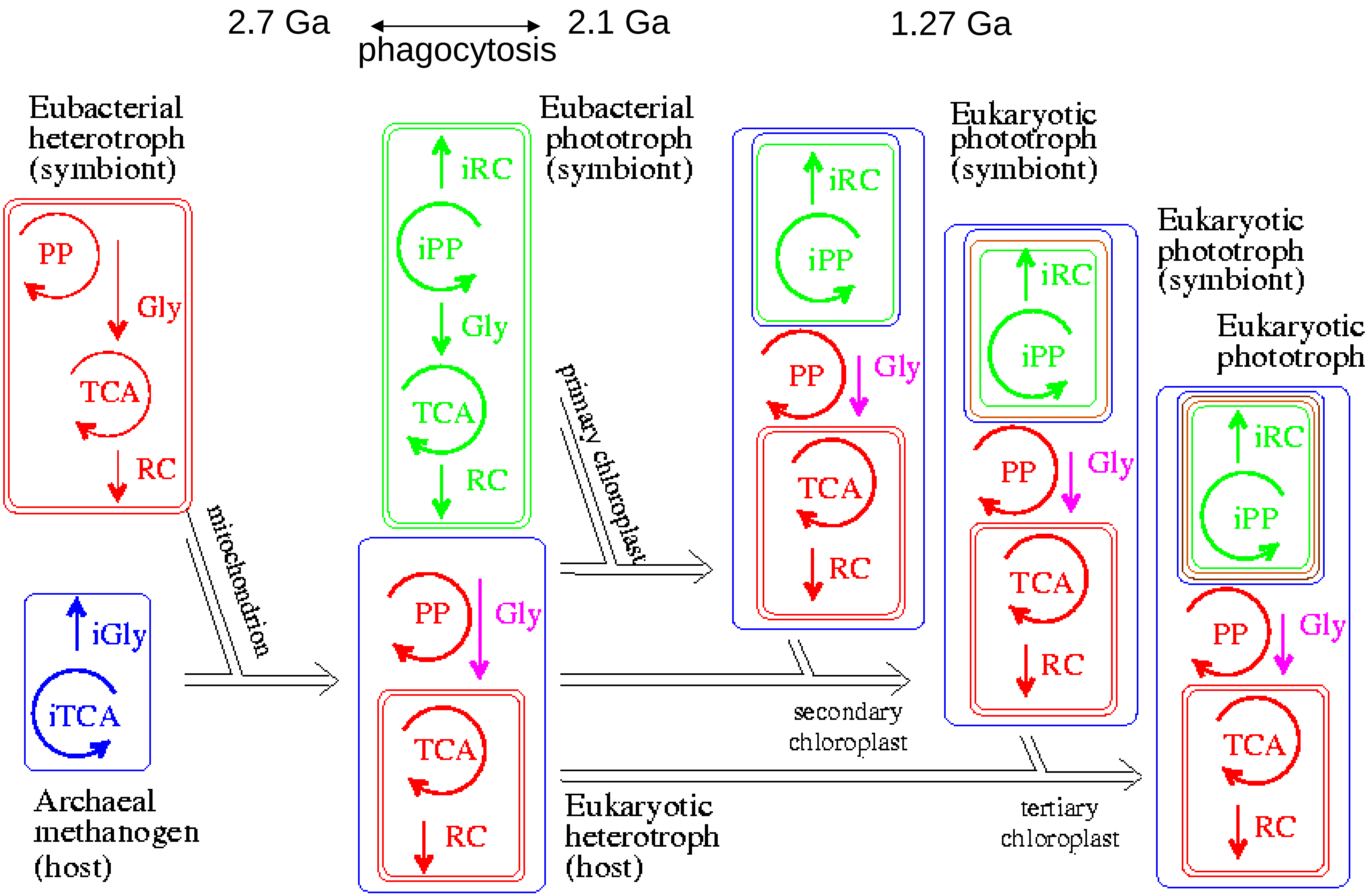
Animal trajectory: biotrophy

- Reduction of number of reserves
- Emergence of life stages
- Further increase of maintenance costs
- Further increase of reserve capacity
- Socialisation
- Supply → demand systems

Plant trajectory: site fixation

- Differentiation of root and shoot
- Emergence of life stages
- Increase of metabolic flexibility (draught)
- Nutrient acquisition via transpiration
- Symbioses with animals, fungi, bacteria
  (e.g. re-mineralisation leaf litter, pollination)

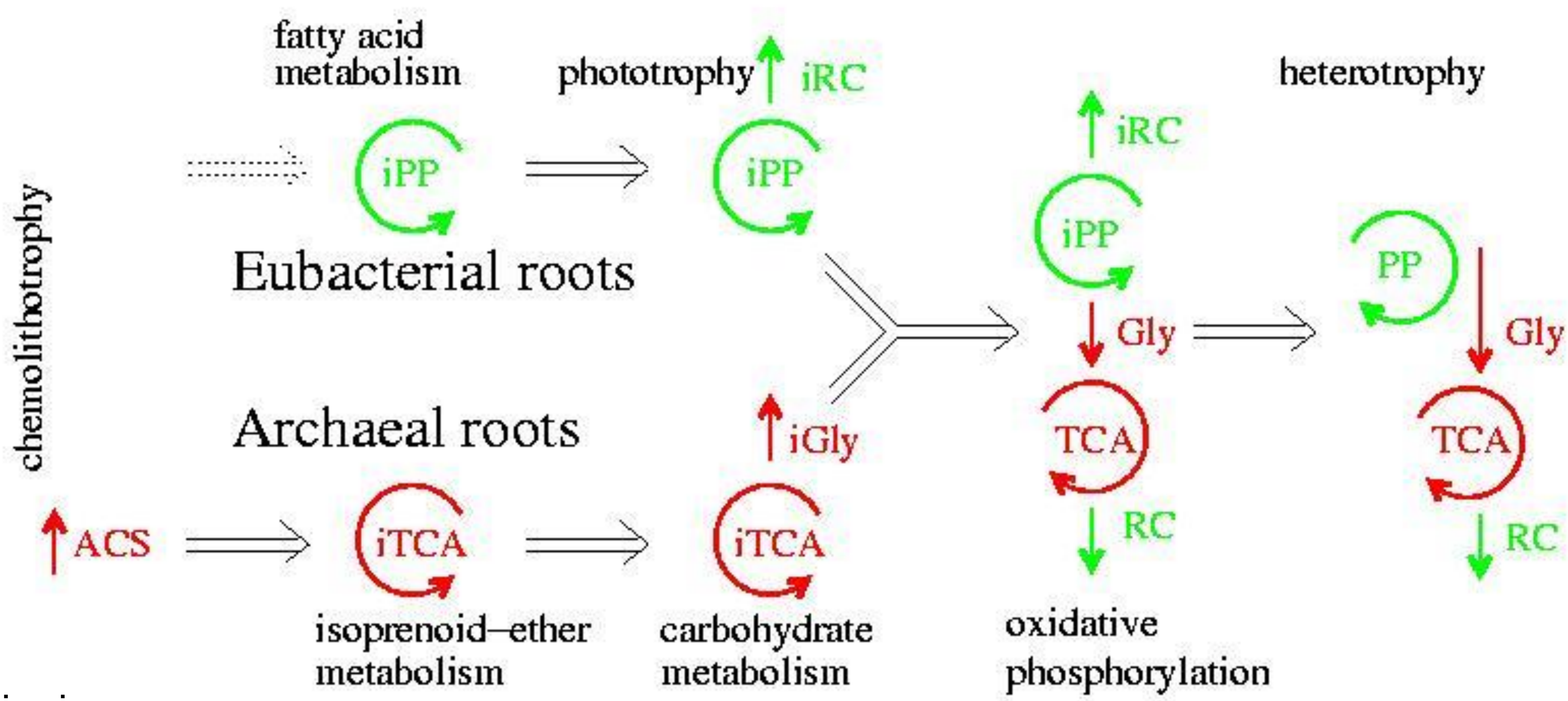
Symbiogenesis 10.4g



Evolution of central metabolism 10.2.1

in prokaryotes (= bacteria)

3.8 Ga 2.7 Ga



i = inverse

ACS = acetyl-CoA Synthase pathway

PP = Pentose Phosphate cycle

TCA = TriCarboxylic Acid cycle

RC = Respiratory Chain

Gly = Glycolysis

Kooijman, Hengeveld 2005

Prokaryotic metabolic evolution 10.2.1a

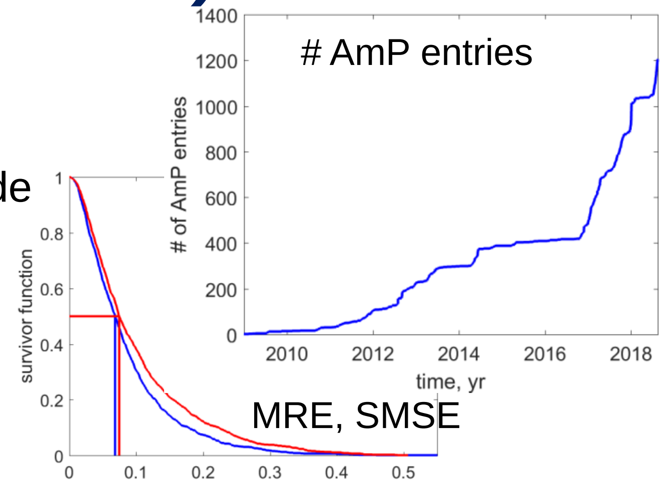
Heterotrophy:
- pentose phosph cycle
- glycolysis
- respiration chain

Phototrophy:
- el. transport chain
- PS I & PS II
- Calvin cycle

Chemolithotrophy
- acetyl-CoA pathway
- inverse TCA cycle
- inverse glycolysis

Add_my_Pet (AmP)

- www.bio.vu.nl/thb/deb/deblab/add_my_pet/
- started in Feb 2009 as exercise in DEB course
- referenced data, par-estimates, implied properties, Matlab code
- now 1208 animal species, all large phyla and chordate orders
- very good fits (mean relative error MRE = 0.07)
- par-point-estimation: minimazation of new loss function
- par-interval-estimation: calibrated loss function profile



Marques et al (2018) The AmP project, *PLoS Comp Biol* 14(5): e1006100
Marques et al (2018) Fitting multiple models to multiple data. *J. Sea Res* doi:10.1016/j.seares.2018.07.004

Altricial–Precocial spectrum

Definition: birth early-late in maturation
DEB quantification: $s_H^{bp} = E_H^b / E_H^p$

In literature applied to birds & mammals
Birds: precocial → altricial
Mammals: altricial → precocial

Augustine et al 2018, J. Sea Res.
Doi: 10.1016/j.seares.2018.03.006
Altricial-precocial spectra in animal kingdom

Altricial–Precocial spectrum

Paleognat
Struthio camelus
ostrich
precocial

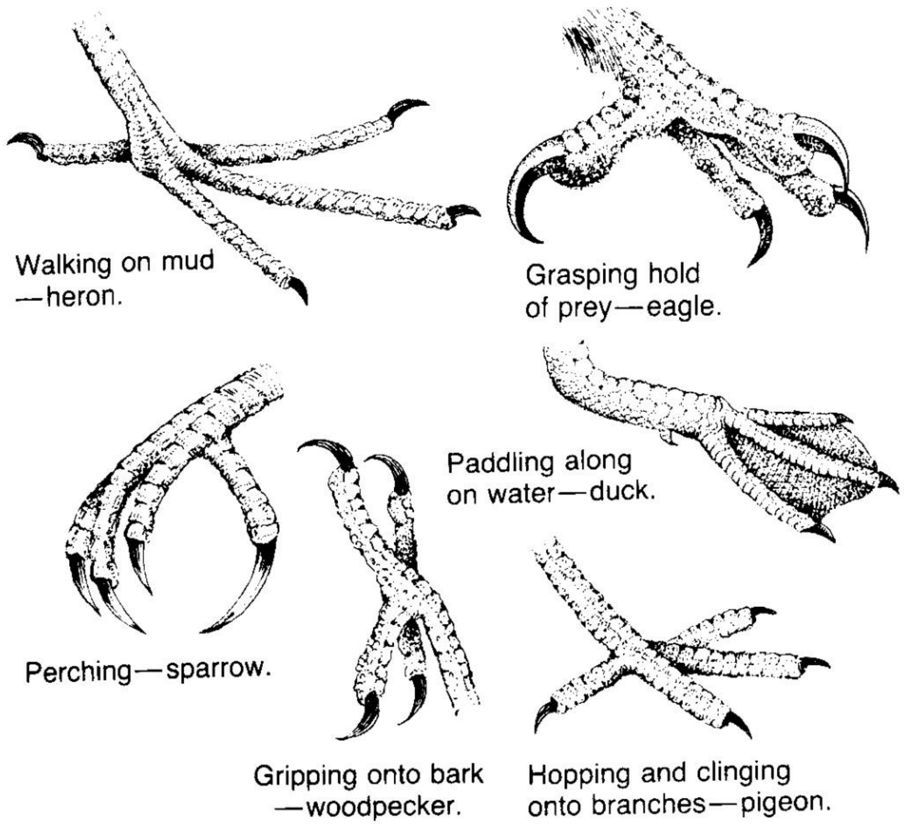
Passerine
Turdus merula
blackbird
altricial

Altricial–Precocial spectrum

Marsupial
Phalanger gymnotis
ground cuscus
altricial

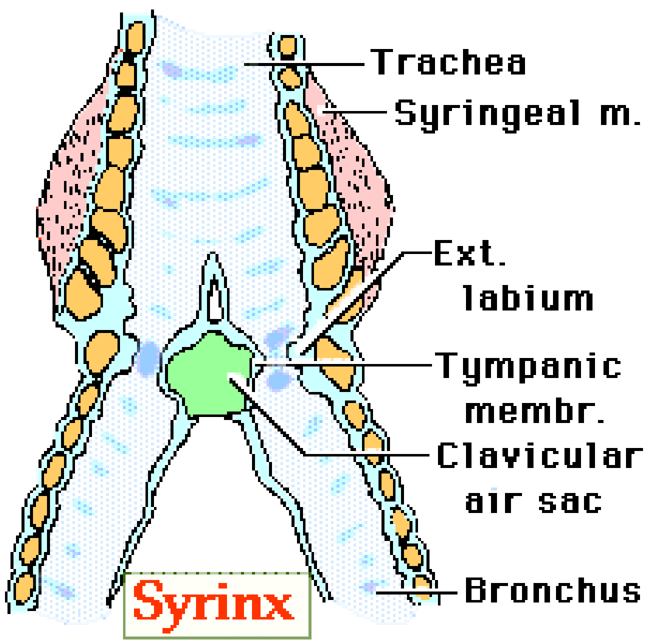
Primate
Carlito syrichta
Phillippine tarsier
precocial

Altricial–Precocial spectrum



Adaptations to life in forest

- anisodactyl feet (perching)
- short round wings
- advanced singing
- altricial development
- high water content of tissues



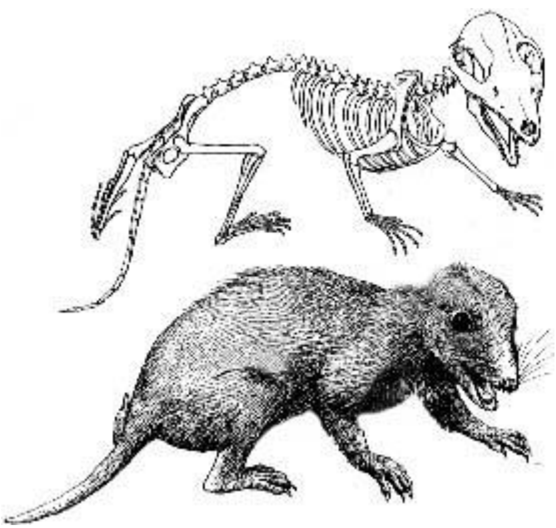
Reptile-Mammal transition 1.1.4b, 7.7

caseine synthetase 200-310 Ma
vitellogenin-encoding lost 30--70 Ma
Brawand *et al* 2008: **Plos Biol 6**:0507

Moschops (*Dinocephalia*)

Cynognathus (*Cynodontia*)

Lystrosaurus (*Dicynodontia*)



Megazostrodon (*Triconodonta*)

Ptilodus (*Multituberculata*)

nursing *Platypus*

Lika et al 2014
J. Theor. Biol.
354:35-47

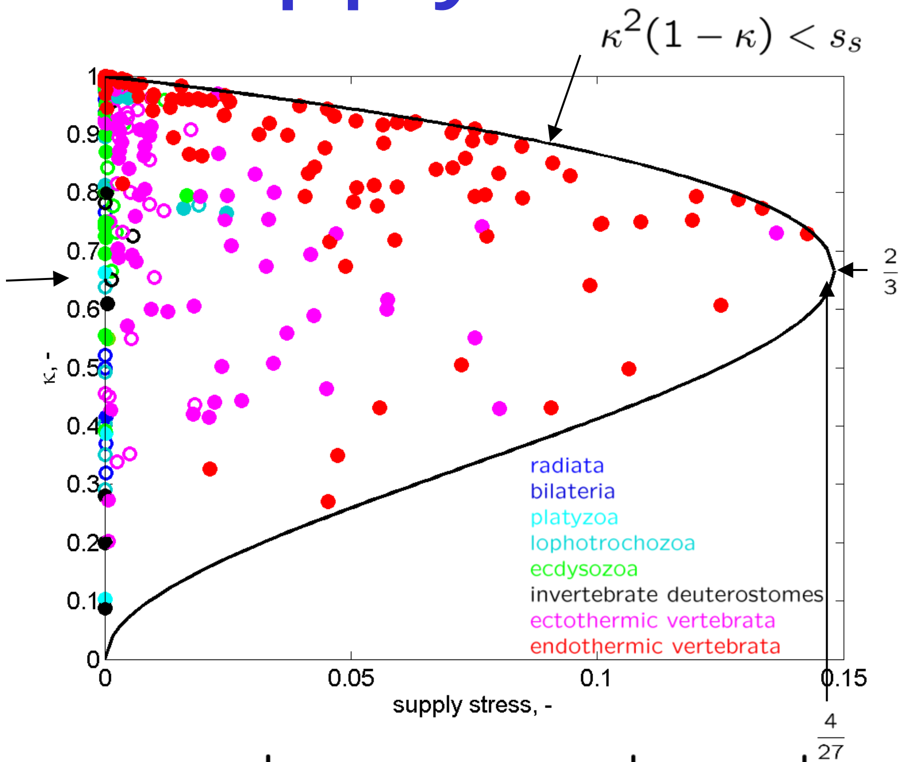
Supply-demand spectrum

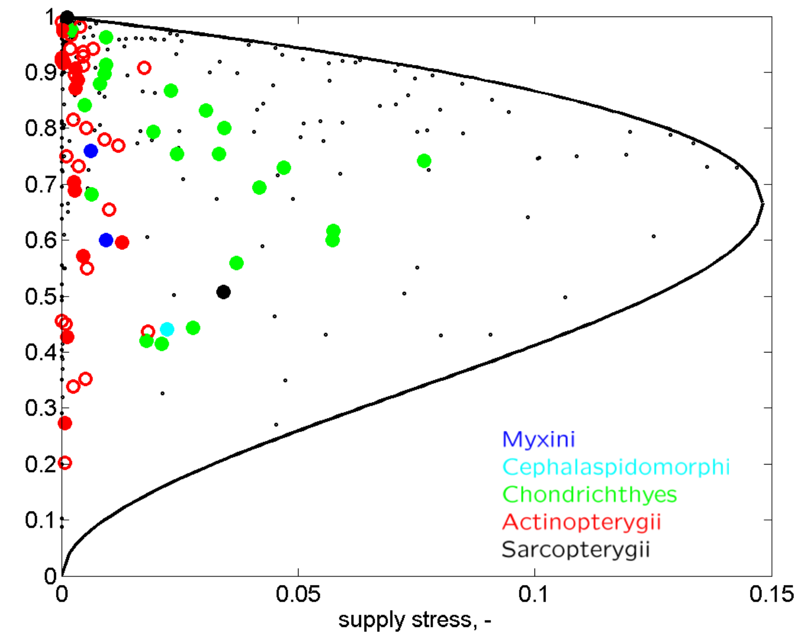
Supply	**Demand**
eat what is available	eat what is needed
high half saturation coefficient	low half saturation coefficient
can handle large range of intake	can handle small range of intake
reserve density varies wildly	reserve density varies little
large range of ultimate sizes	small range of ultimate sizes
survives some shrinking well	survives shrinking badly
physiological birth control	behavioural birth control
low peak metabolic rate	high peak metabolic rate
open circulatory system	closed circulatory system
iso- & centro-lecithal eggs	a- & telo-lecithal eggs
rather passive, simple behaviour	rather active, complex behaviour
sensors less developed	sensors well developed
typically ectothermic	typically endothermic
evolutionary original	evolved from supply systems
has demand components (maintenance)	has supply components (some food must be available)

metabolic control external   metabolic control internal

Lika et al 2014
J. Theor. Biol.
354:35-47

Supply-demand spectrum 10.5.5





0 supply ⟷ demand

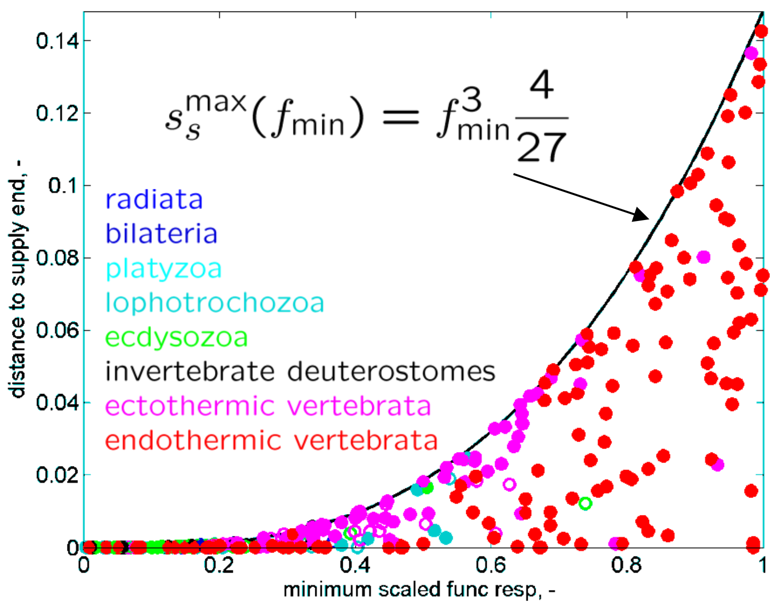
$$\dot{R}_m > 0 \rightarrow s_s < \frac{\dot{k}_J E_H^p [\dot{p}_M]^2}{f^3 s_{\mathcal{M}}^3 \{\dot{p}_{Am}\}^3} = \frac{\dot{p}_J \dot{p}_M^2}{\dot{p}_A^3}$$

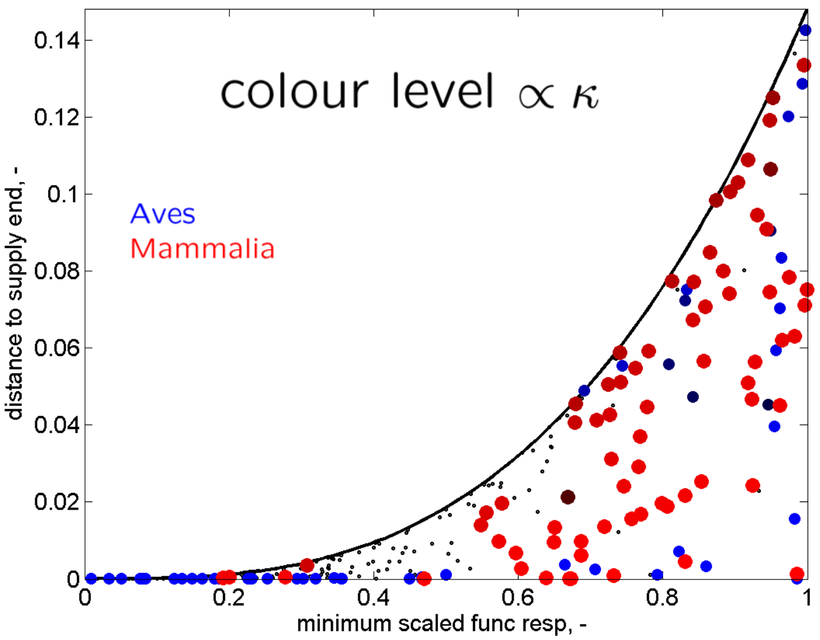
$$s_s + s_d = \frac{4}{27}$$

κ	allocation fraction	$\dot{R}_m$	max reproduction
$\dot{k}_J$	mat maint rate coeff	E_H^p	maturity at puberty
$[\dot{p}_M]$	spec somatic maint	f	scaled func resp
$s_{\mathcal{M}}$	acceleration factor	$\{\dot{p}_{Am}\}$	spec max assimilation
$\dot{p}_J$	maturity maint	$\dot{p}_M$	somatic maint
$\dot{p}_A$	assimilation rate		

Lika et al 2014
J. Theor. Biol.
354:35-47

Supply-demand spectrum





s_s	distance to supply-end
f_{min}	min f to reach puberty

Thank you, organisors, for inviting me

Thank you, audience, for your attention

Any questions?

DEB2017 Tromsø had 122 participants →
Course Parts: Tele, School, Symposium
Secial issue: J Sea Res 2018

DEB2019 Brest
https://deb2019.sciencesconf.org

DEB newsletter: Laure.Pecquerie@ird.fr