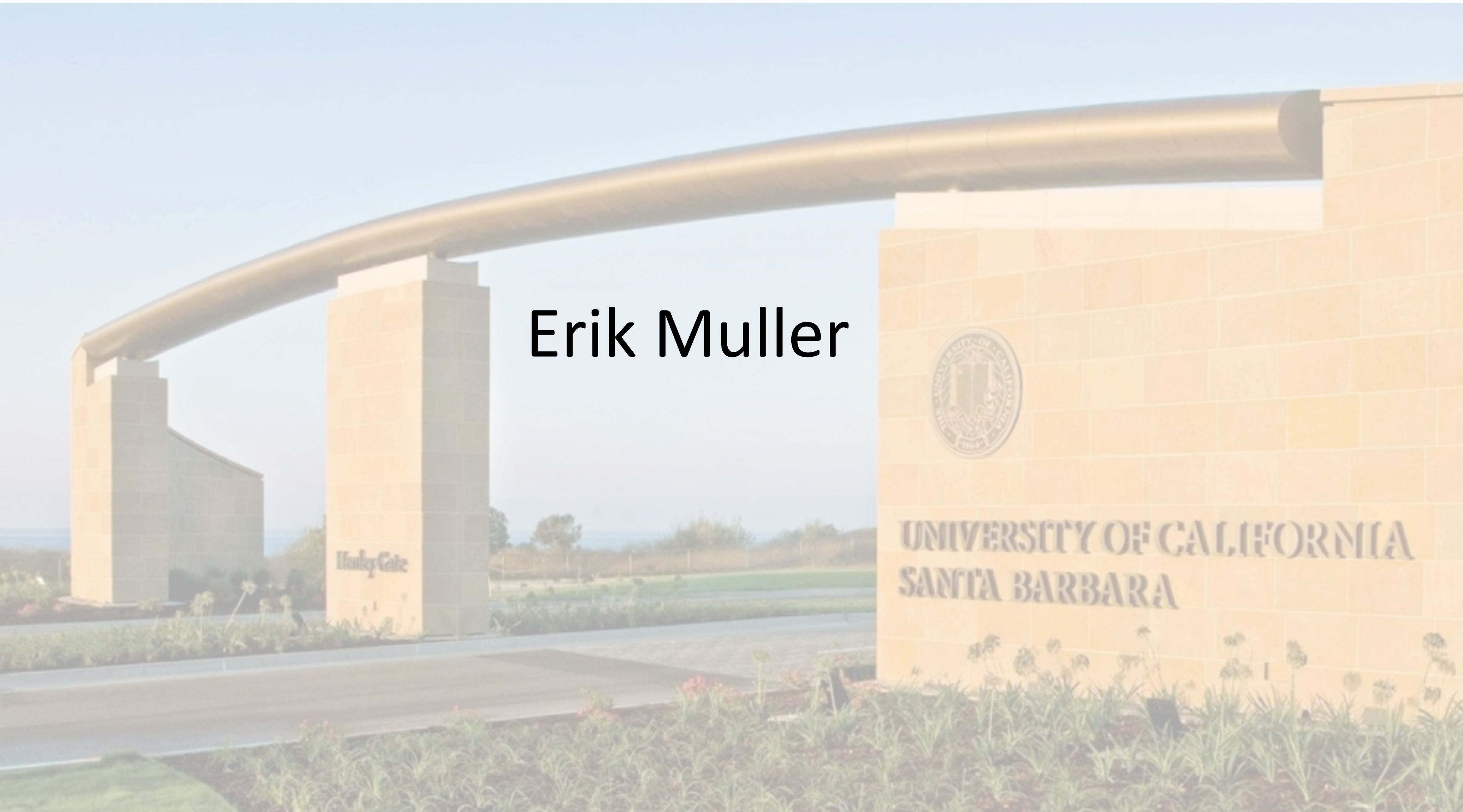
# Demand driven reserve allocation: can the reproductive buffer modulate kappa?

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NIMBioS National Institute for Mathematical and Biological Synthesis

NSF

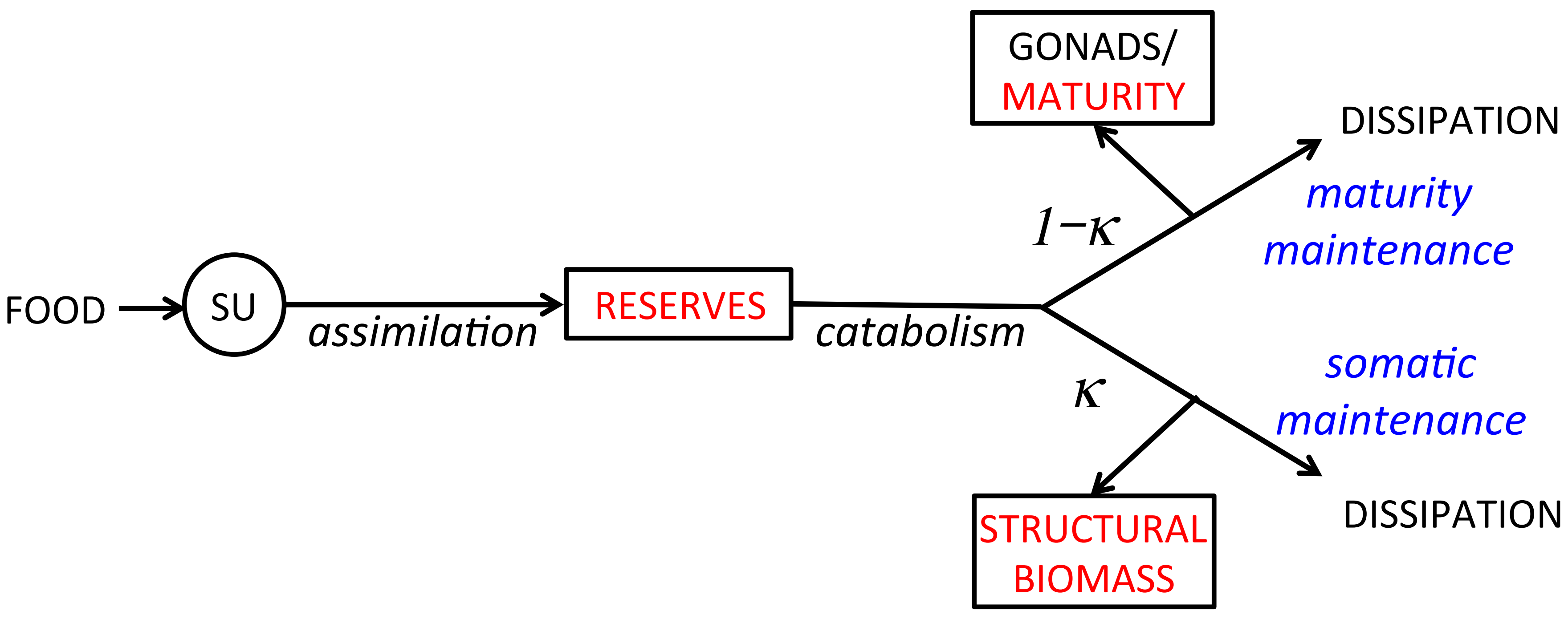
United States Environmental Protection Agency

# OUTLINE

- Why think about ‘demand driven reserve allocation’?
- 2 models
  - Extension of standard DEB
  - Kappa regulated by gonads (e.g. hormones)
- Evaluation with rainbow trout
- Interesting model behavior

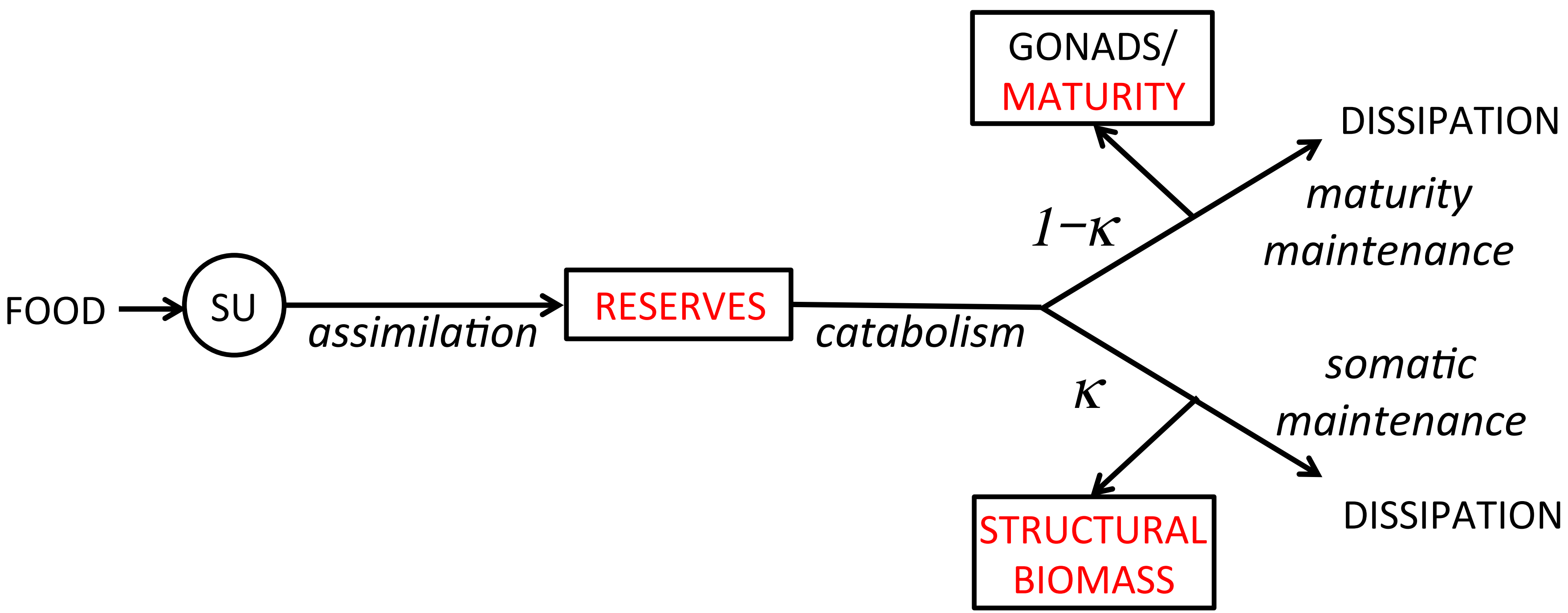
# STANDARD DEB: mostly a supply driven system

## Maintenance demand driven



# STANDARD DEB: no explicit regulation mechanisms

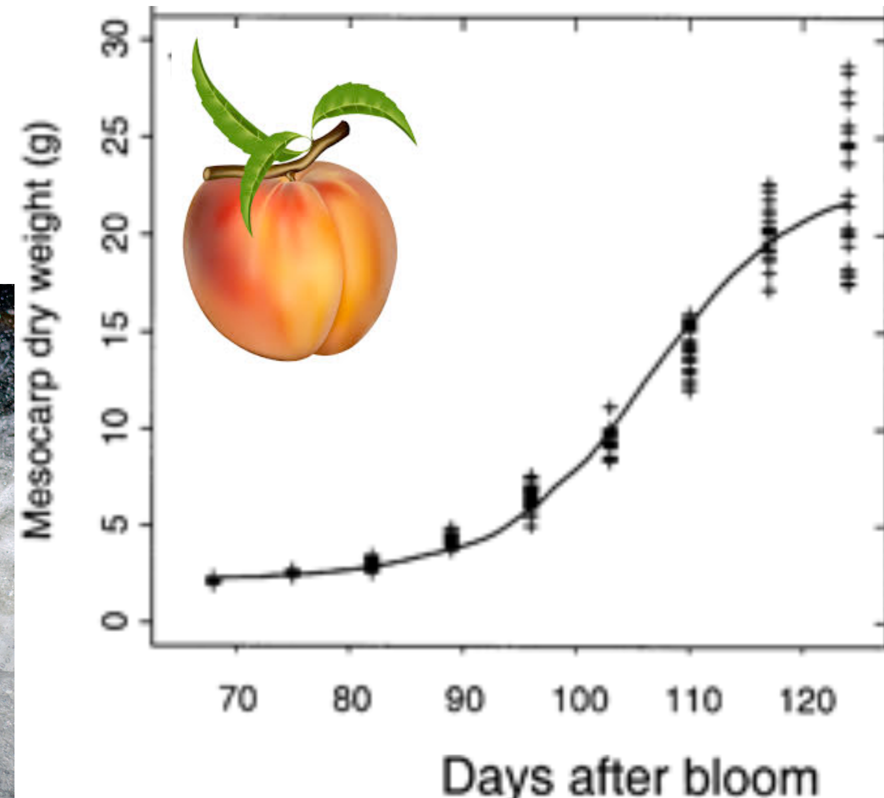
κ IS CONSTANT



# How to describe seasonal reproductive cycles?
# Semelparity?
# Impact of endocrine disruptors?

*www.secore.org*

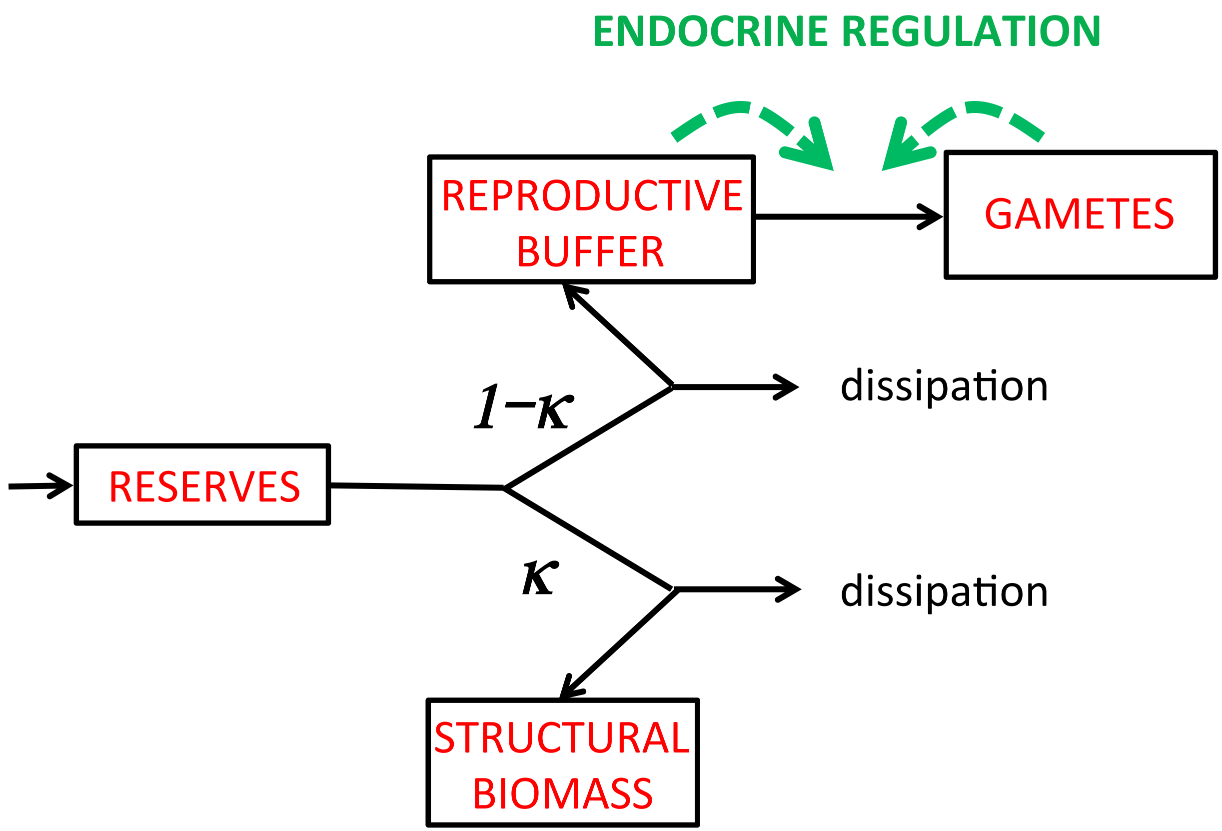
*www.critfc.org*



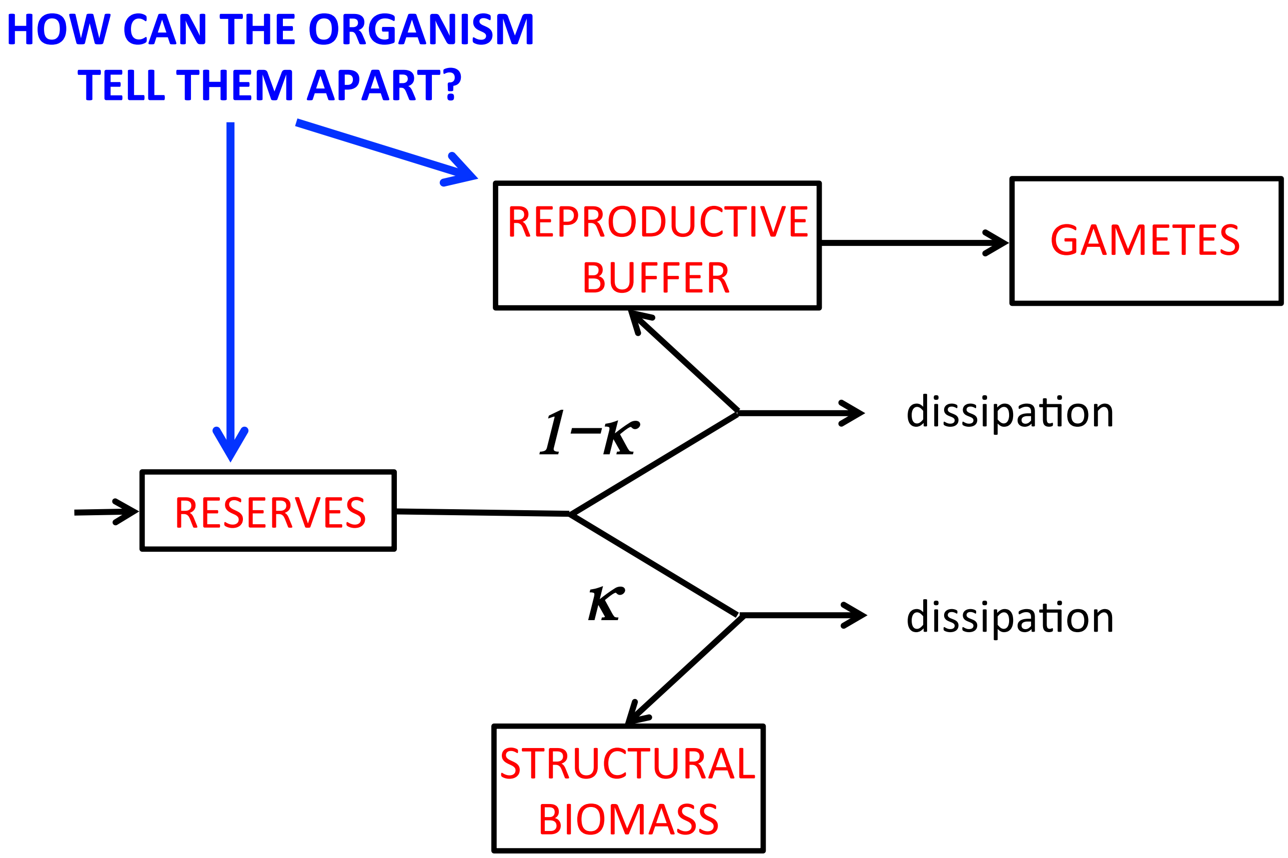

*Lobit et al (2003) J Exp Bot*

# Reproductive structures can produce hormones that regulate the supply of reserves to themselves

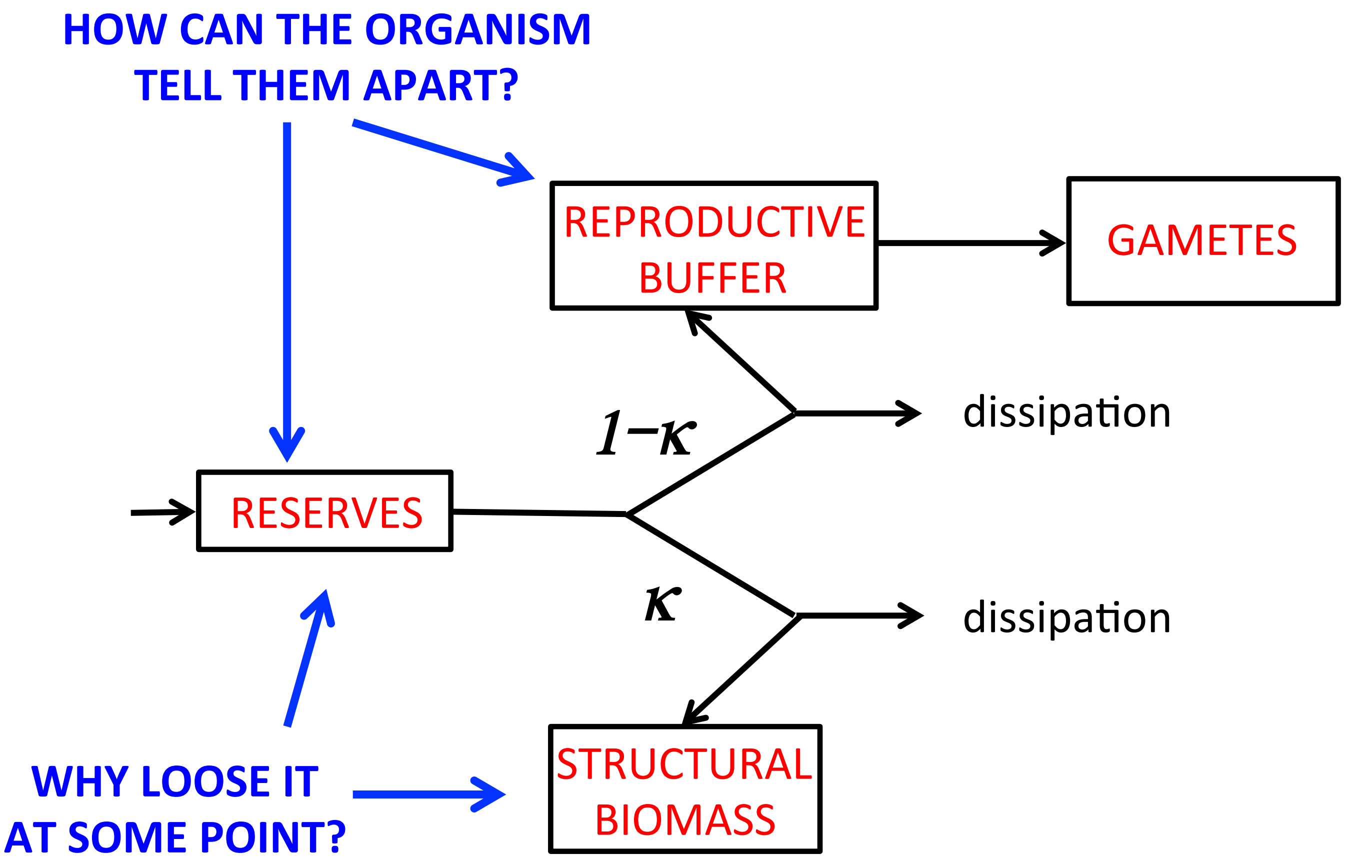
# GONAD LOADING MODULE – stDEB+



# SOME REMAINING QUESTIONS



# SOME REMAINING QUESTIONS

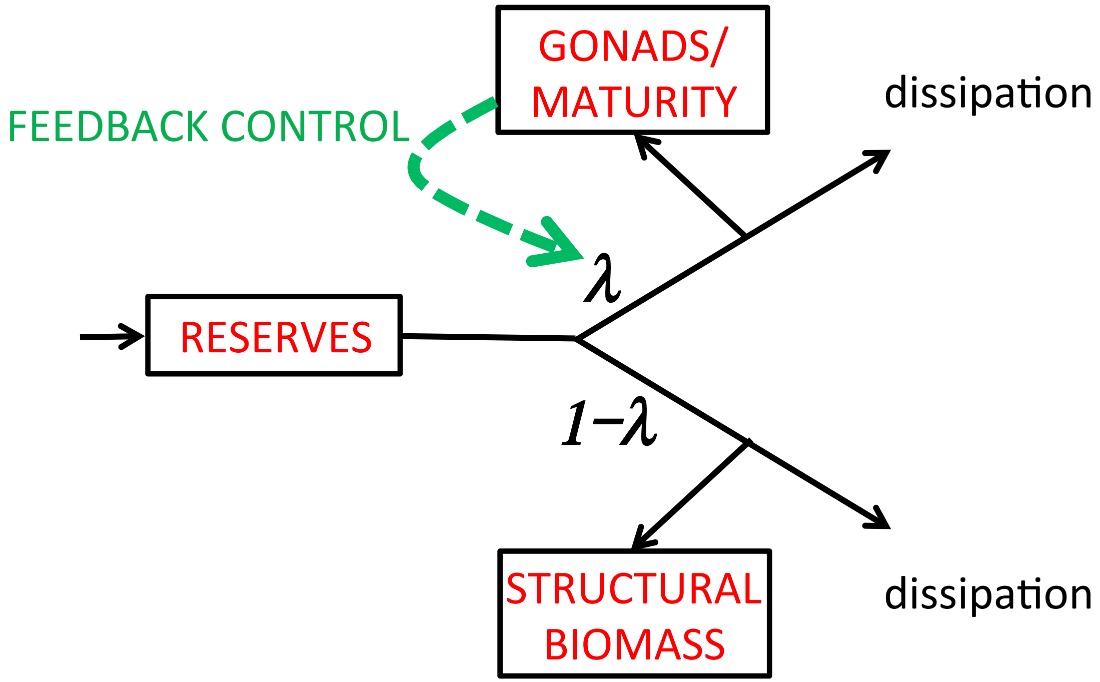


# RECYCLING/ DEGENERATION OF STRUCTURE


**DEGENERATION OF ALIMETARY TRACT IN SEMELPAROUS FISH**

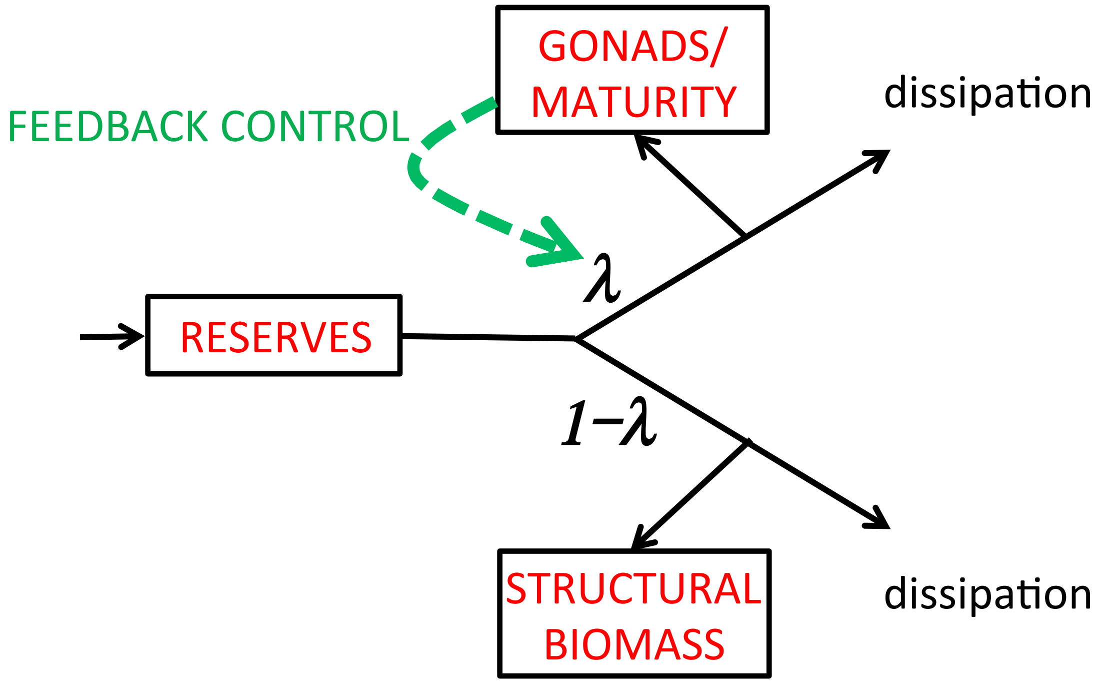
**DEGENERATION OF FLIGHT MUSCLES IN ADULT INSECTS**

# DEMAND DRIVEN ALLOCATION OF RESERVES TO REPRODUCTION (and maturation) - dDEB




$$\lambda = 1 - \kappa$$

# DEMAND DRIVEN ALLOCATION OF RESERVES TO REPRODUCTION (and maturation) - dDEB

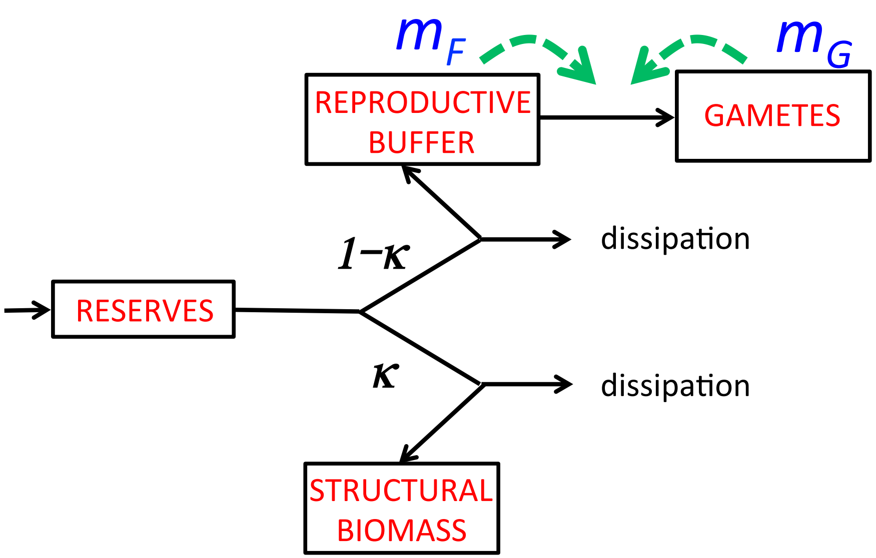



*λ is proportional to:*

- *density of reproductive matter,* $m_F$
- *difference between a theoretical maximum and actual density of reproductive matter,* $m_{Fmax}$

$$\lambda = \frac{4\lambda_{\max} m_F \left(m_{F\max} - m_F\right)}{m_{F\max}^2}$$

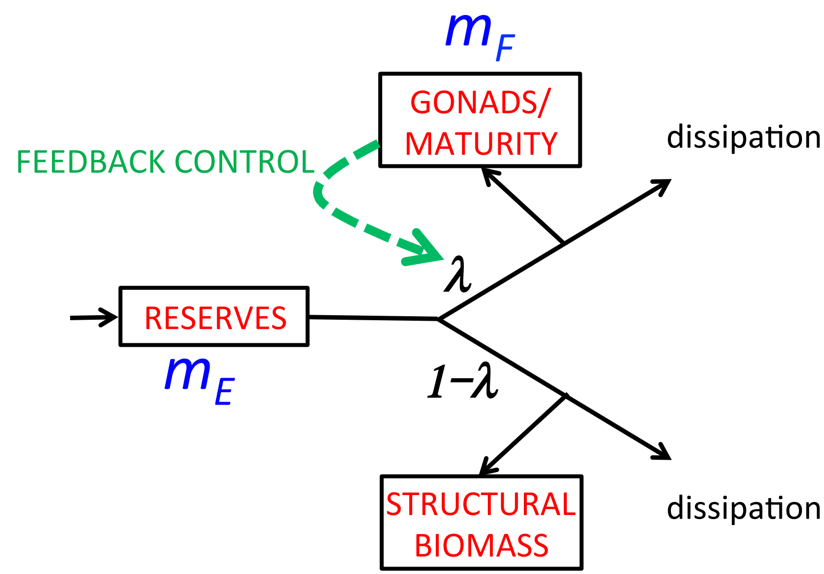
## stDEB+




$$\frac{dm_G}{dt} = A y_{GF} \lambda k_F m_F - j_V m_G$$

$$\lambda = \frac{4\lambda_{\max} m_G \left( m_{G\max} - m_G \right)}{m_{G\max}^2}$$

## dDEB

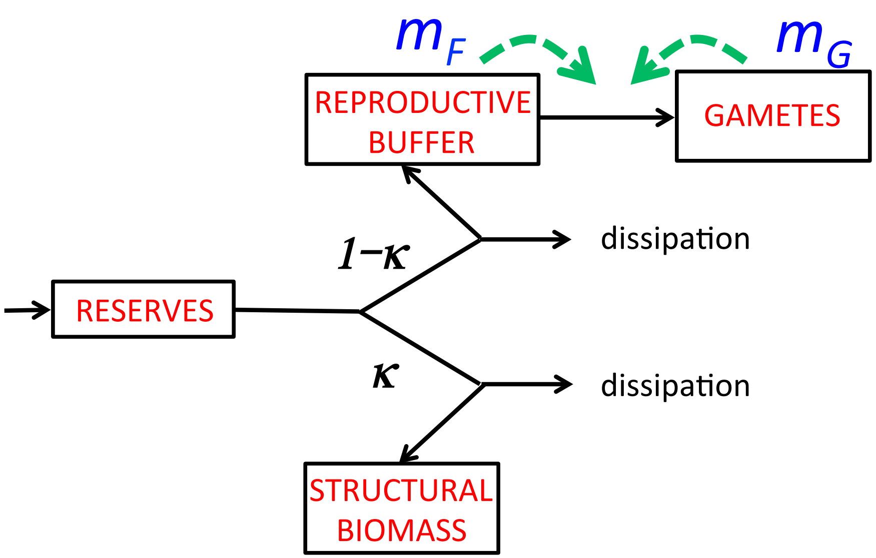



$$\frac{dm_F}{dt} \approx y_{FE} \lambda \, m_E \left( k_E S - j_V \right) - j_V m_F$$

$$\lambda = \frac{4\lambda_{\max} m_F \left( m_{F\max} - m_F \right)}{m_{F\max}^2}$$

*Spawning trigger*

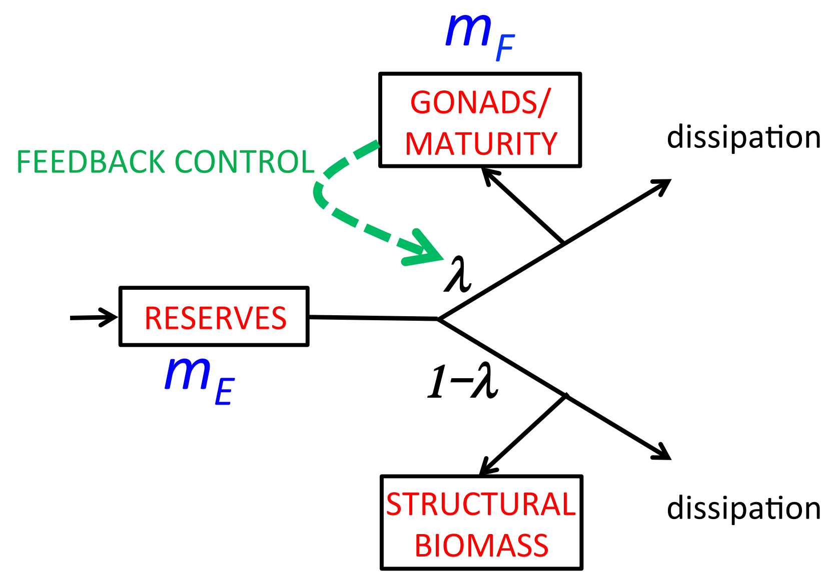
## stDEB+




$$\frac{dm_G}{dt} = A y_{GF} k_F m_F \lambda - j_V m_G$$

$$A = \left(t > t_{\min}\right)\left(m_F > m_{F\min}\right)$$

## dDEB




$$\frac{dm_F}{dt} \approx y_{FE} \lambda\, m_E \left(k_E S - j_V\right) - j_V m_F$$

$S$ : shape correction factor

$\approx$ : left out maturity maintenance

# EVALUATION WITH RAINBOW TROUT

## ‘stripped’ 2 yo females → 1 year constant T, food

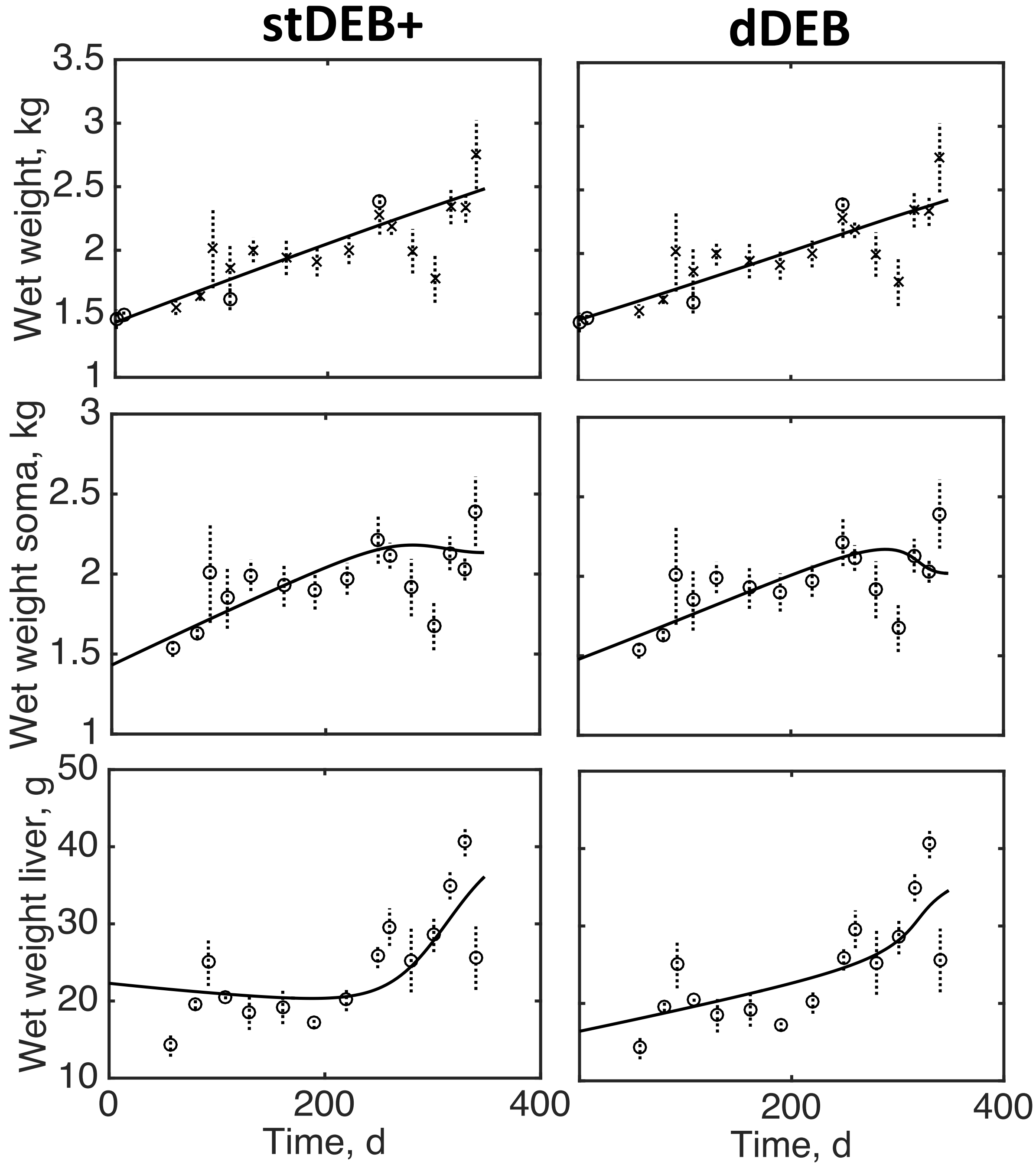
- Parameterize with elaborate data set (Gillies *et* al. (2016) )DOI:10.1371/journal.pcbi.1004874) and Add-My-Pet (AMP)
  - Biomass: total, ovaries, liver
  - Plasma content: vitellogenin, estradiol
  - Egg diameter
- Predict data from 2 sparser data sets (unpublished)
  - Biomass, GSI, egg measures

# EVALUATION WITH RAINBOW TROUT

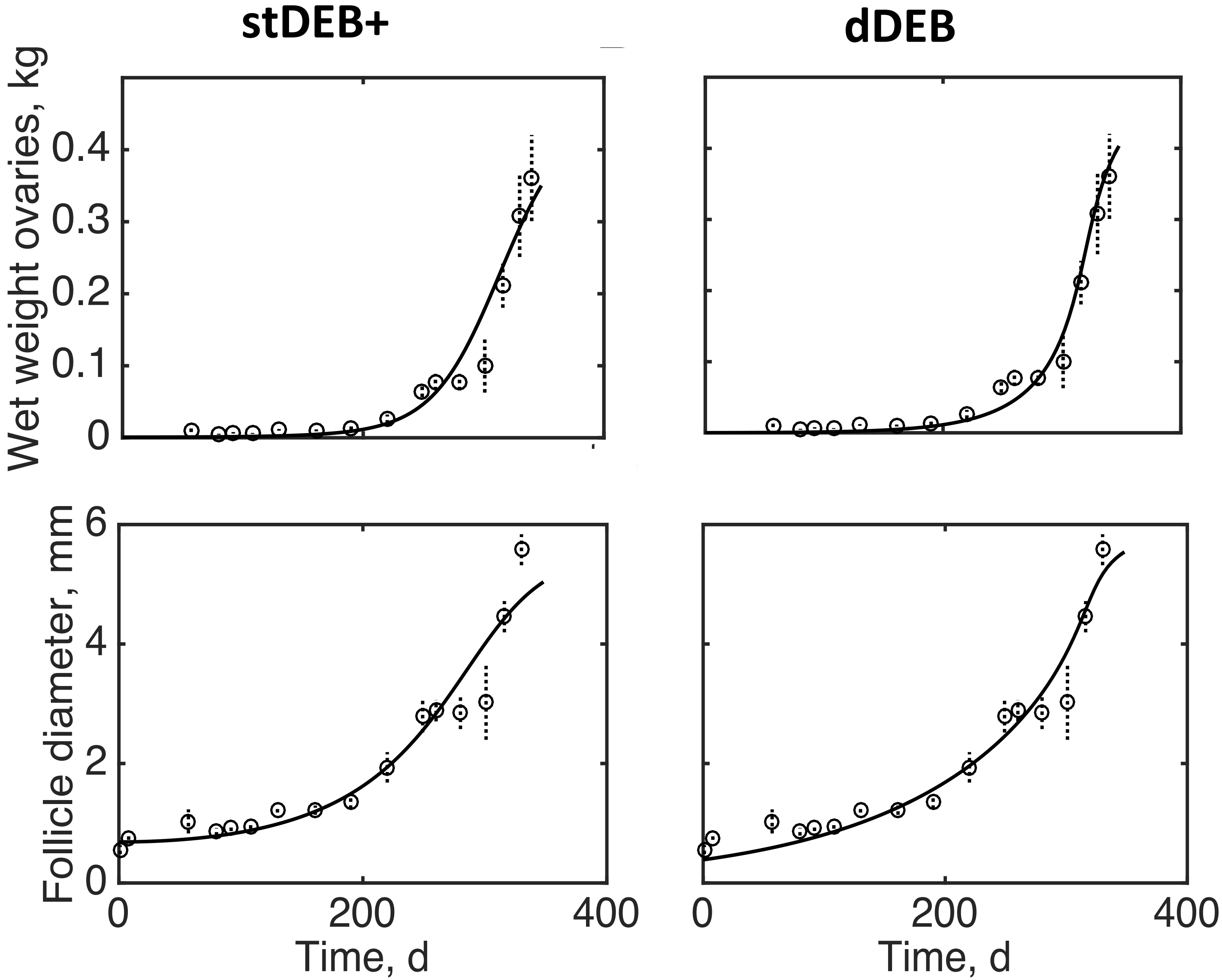
‘stripped’ 2 yo females → 1 year constant T, food

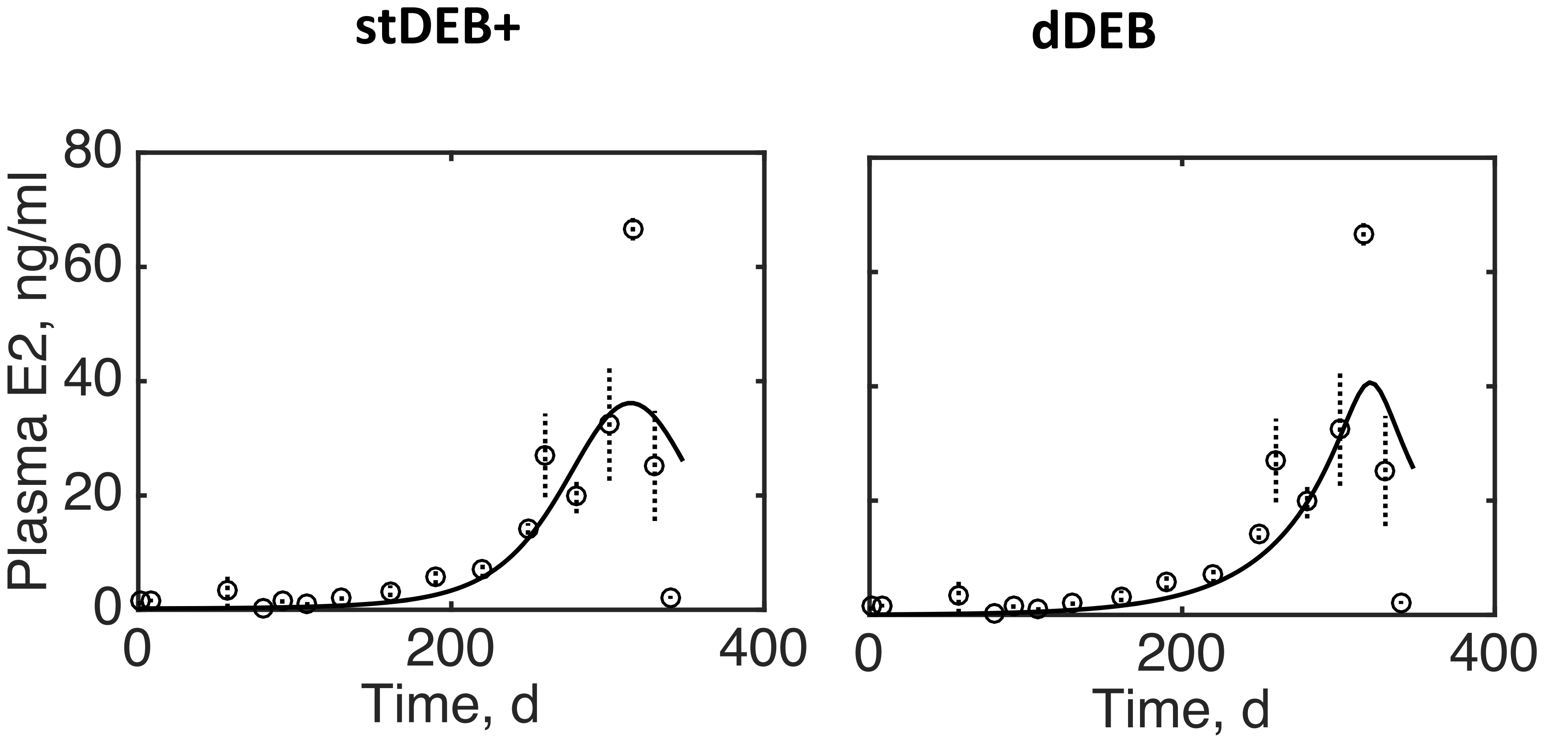
Estradiol is produced by the ovaries

$$\lambda \propto \text{ plasma estradiol concentration}$$



stDEB+
dDEB
Wet weight, kg
Wet weight soma, kg
Wet weight liver, g
Time, d
Time, d
3.5
3
2.5
2
1.5
1
50
40
30
20
10
0
200
400


stDEB+
dDEB
Wet weight ovaries, kg
0
0.1
0.2
0.3
0.4
Follicle diameter, mm
0
2
4
6
0
200
400
Time, d
0
200
400
Time, d



stDEB+
dDEB
Plasma E2, ng/ml
80
60
40
20
0
0
200
400
Time, d
0
200
400
Time, d

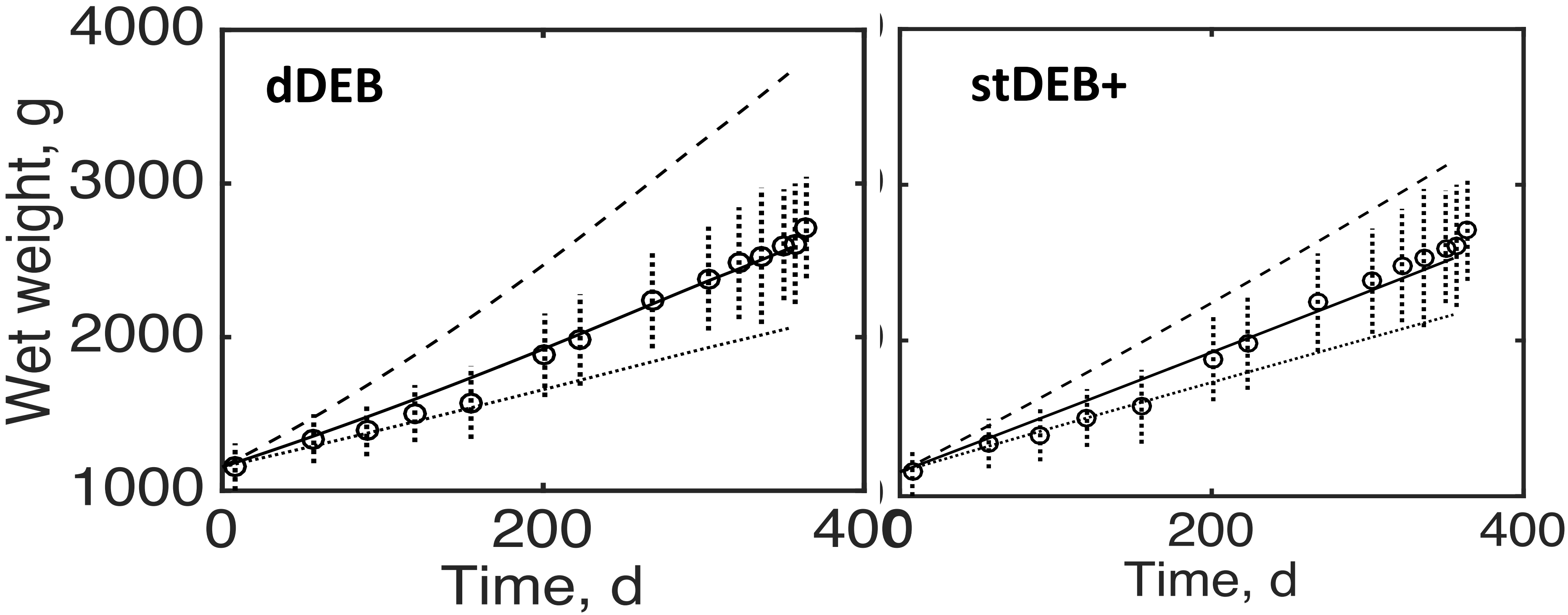
# Parameter estimation

| | stDEB | dDEB | AMP |
|---|---|---|---|
| # Parameters | 14[1] | 12[1] | 9[2] |
| Parameters/ data set | 2.0 | 1.7 | - |
| | | | |
| $k_E$, 1/d | 1.9E-03 | 1.6E-03 | 2.7E-03 |
| $\kappa$ | 0.36 | - | 0.69 |
| $\lambda_{max}$ | 0.58 | 0.73 | - |
| $m_{Fmax}$ or $m_{Gmax}$ | 3.35 | 2.12 | < 3 |
| Number of eggs x 1000 | 5.23 | 4.53 | |
| | | | |
| ln likelihood | -1570 | -1555 | - |

[1]free

[2]fixed and $f$ = 0.9; $k_J$ = 0; $t_{min}$ and $m_{Fmin}$ = 0

# Projection mean wet weight data set 2



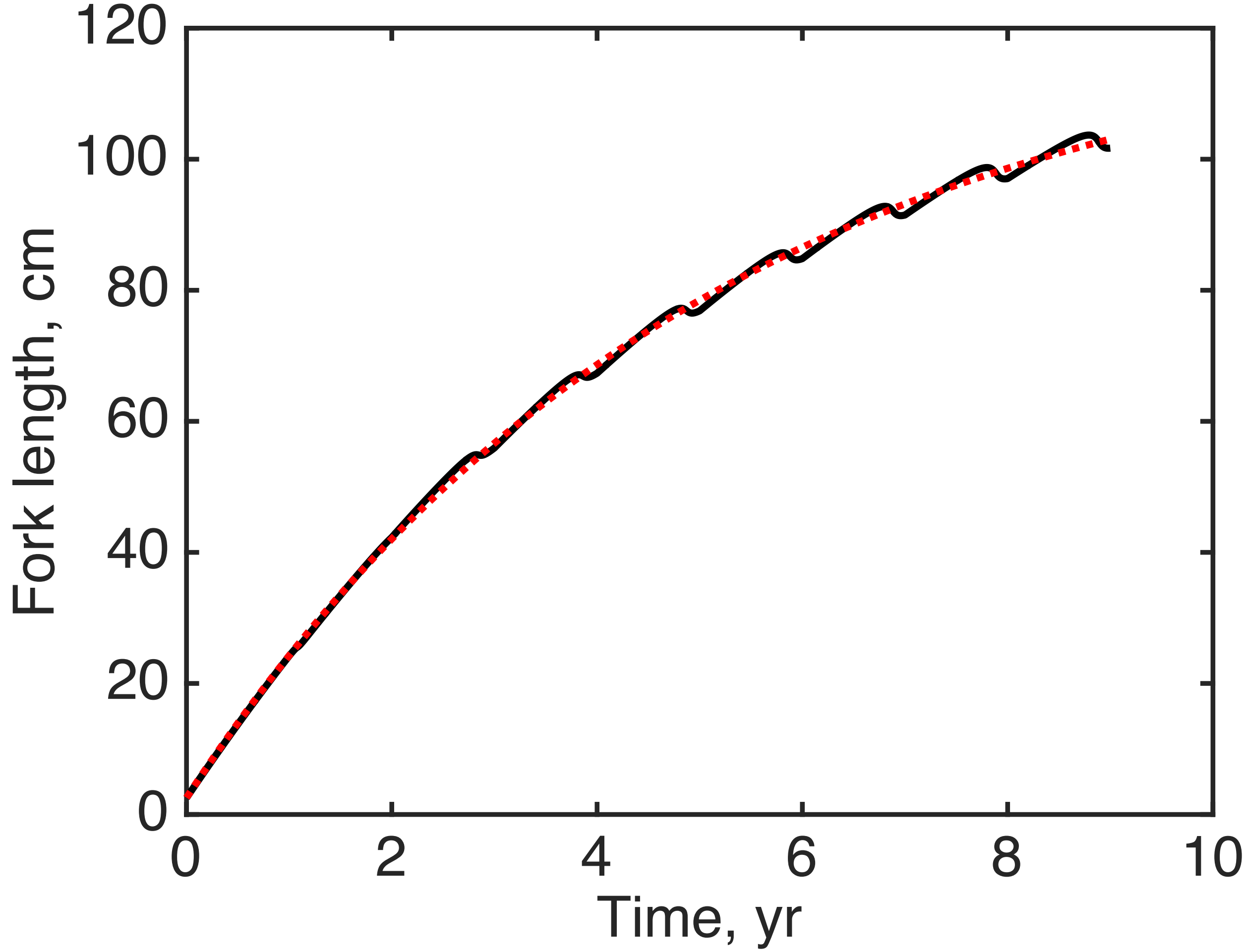

Broken line: $k_E$ = 2.7E-3 (from AMP)
Solid line: $k_E$ = 2.0E-3
Dotted line: $k_E$ = 1.6E-3 (from data set 1)

# Projection GSI and egg size

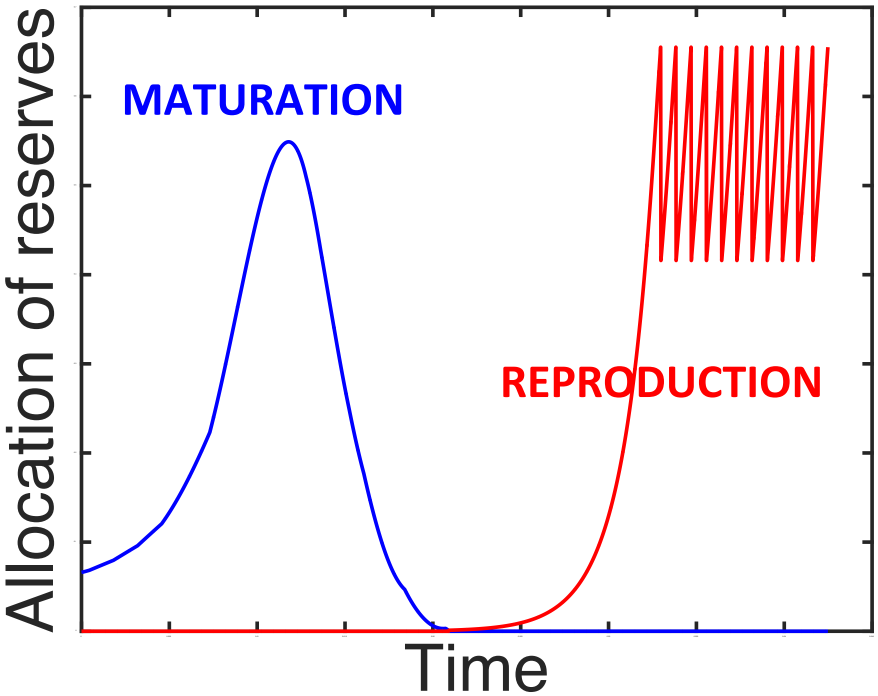
| | | Set 1 | Set 2 | | | Set 3 | | |
|---|---|---|---|---|---|---|---|---|
| | | data | data | dDEB estimate | stDEB estimate | data | dDEB estimate | stDEB estimate |
| | | | | $k_E$ = 2e-3 | $k_E$ = 2e-3 | | $k_E$ = 2e-3 | $k_E$ = 2.7e-3<br>$f$ = 0.8 |
| **GSI** | **Ovary/ body weight** | **0.131** | | | | | | |
| | **Egg mass/ body weight** | | **0.105** | **0.176** | **0.148** | **0.169** | **0.181** | **0.161** |
| **Eggs** | **Wet weight, mg** | | | | | **105.68** | **91.61** | **77.07** |
| | **Diameter, mm** | | | | | **5.54** | **5.58** | **5.26** |

# INTERESTING MODEL BEHAVIOR I

Long-term growth: 'dDEB-trout' (——) versus von Bertalanffy (·······)



# INTERESTING MODEL BEHAVIOR II

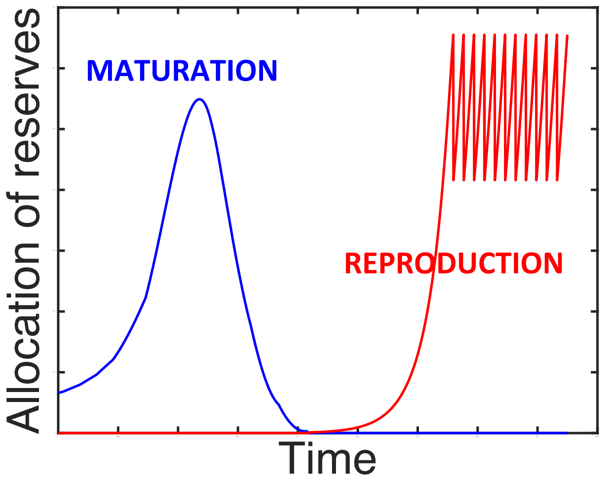


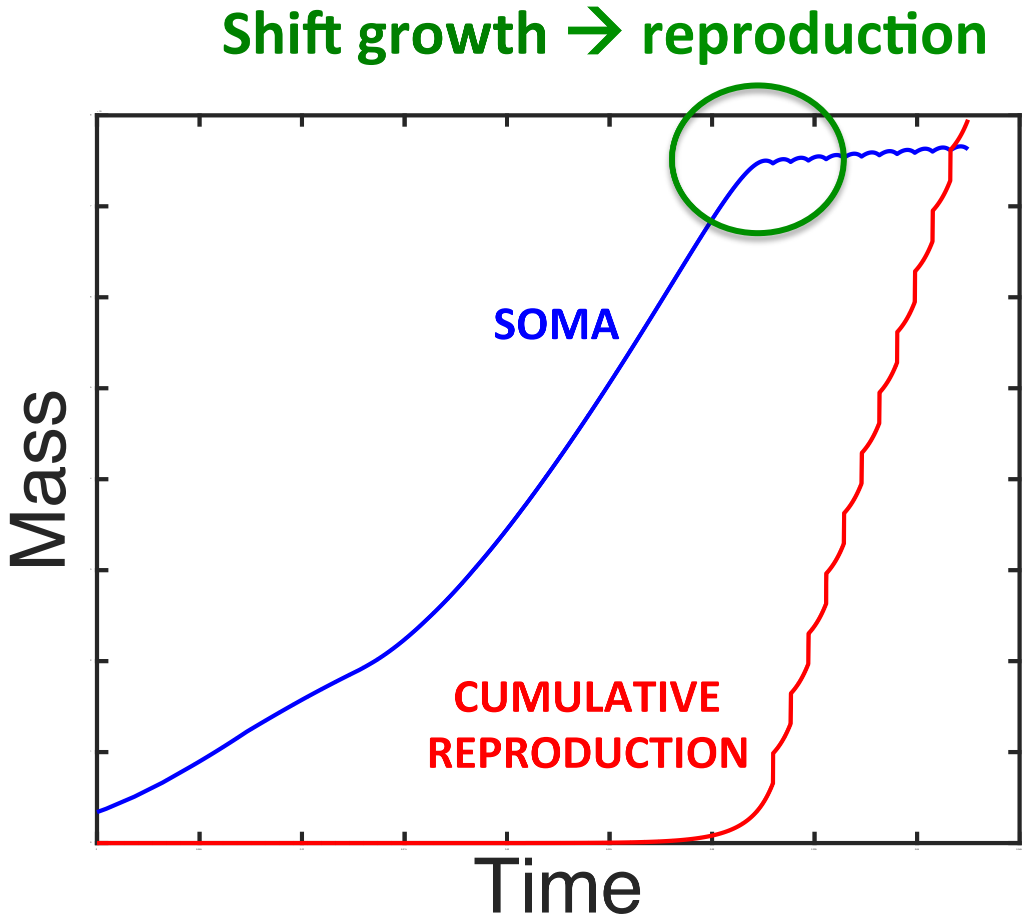

Partial release of gonads

↓

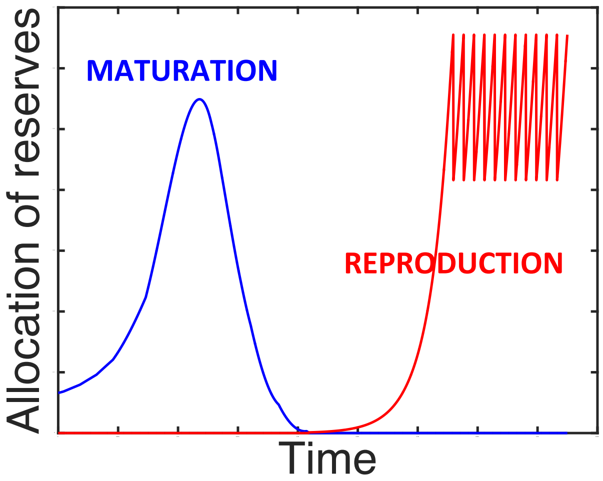
Less variability in λ

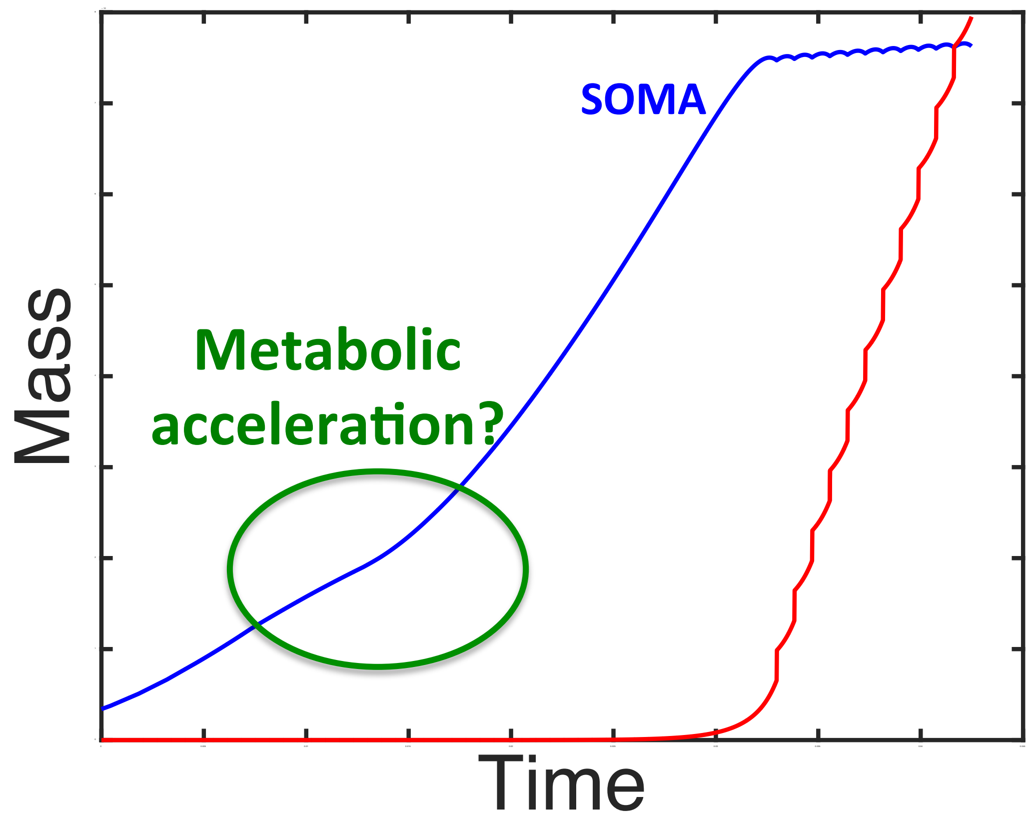
# INTERESTING MODEL BEHAVIOR III



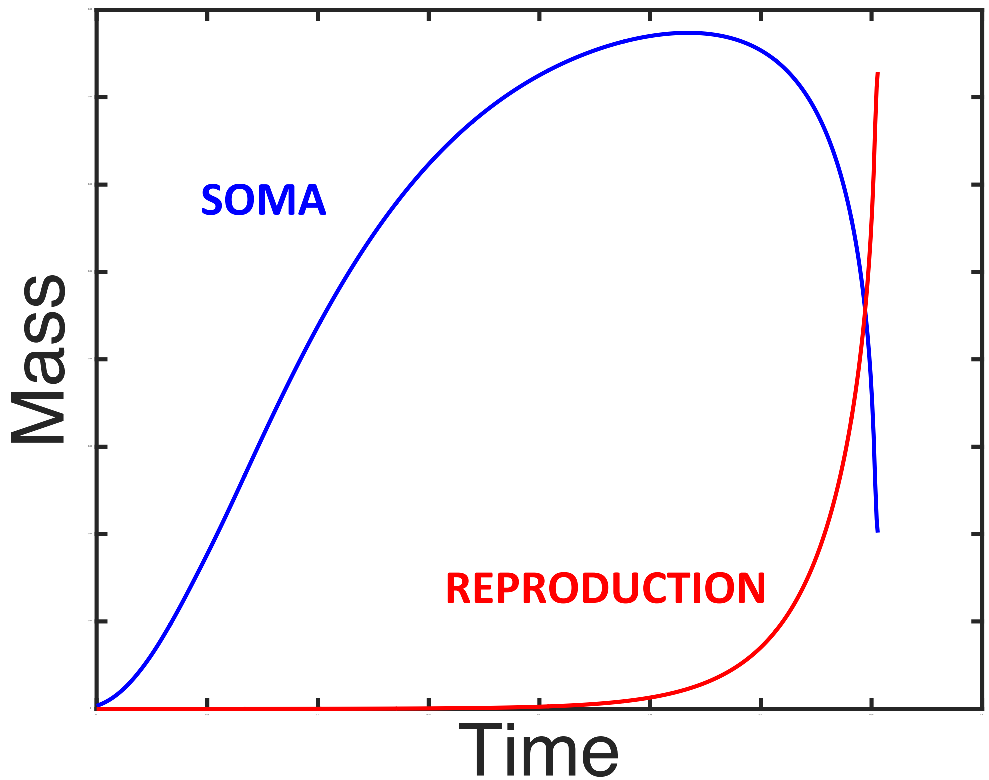
# INTERESTING MODEL BEHAVIOR IV



# INTERESTING MODEL BEHAVIOR V

Degradation of structural biomass at high $\lambda_{max}$




Note: *f* is constant

Indirect mechanism: $M_V$ ⬇ → $m_F$ ⬆ → λ ⬆

# Conclusions

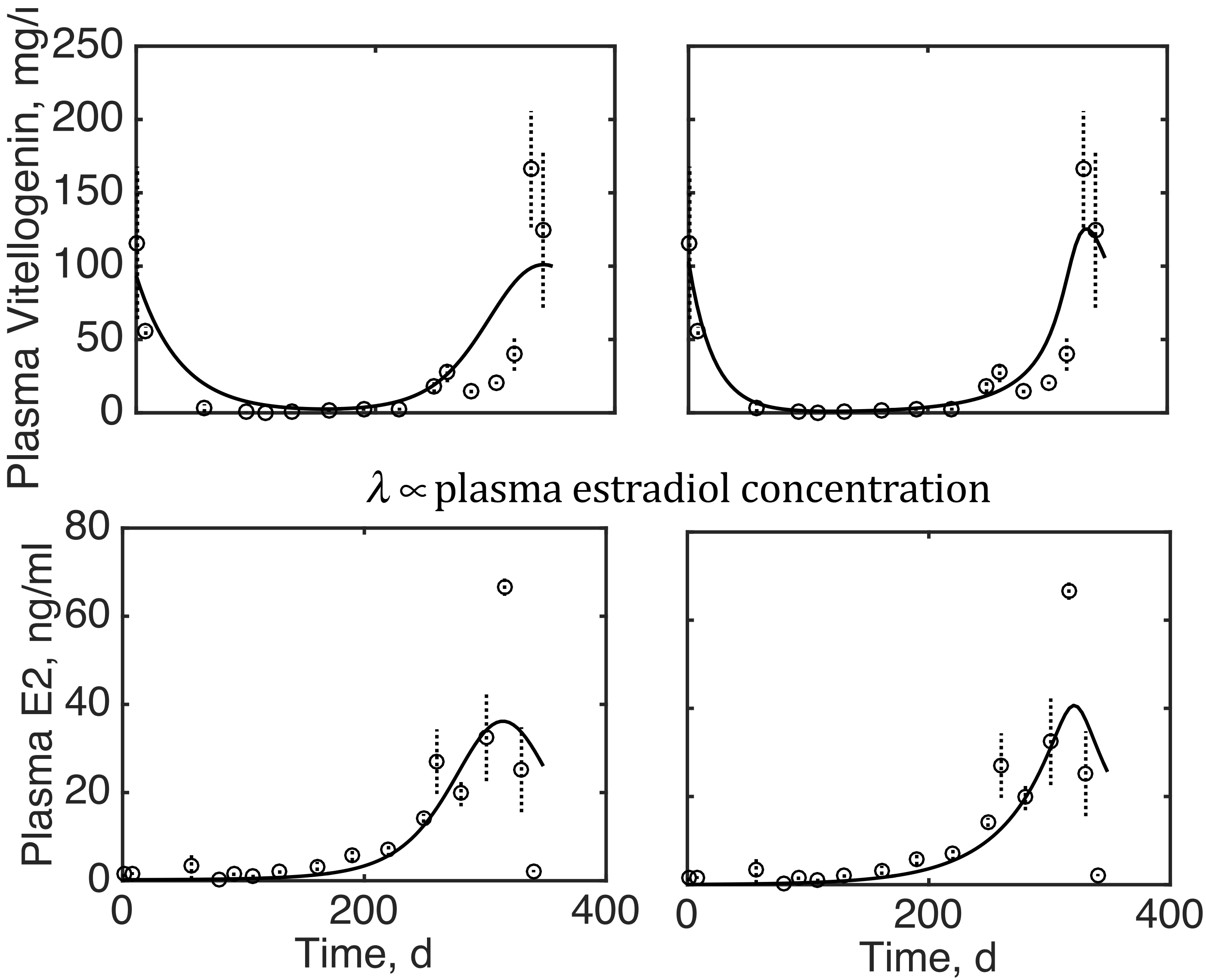
- DEB with demand driven reserve allocation fits data on 2→3 year old trout (growth, reproduction, estradiol, vitellogenin) better than stDEB with egg load module
  - Higher likelihood & less parameters
- Versatile behavior
  - Approx. von Bertalanffy → 'Bang-Bang'
  - Metabolic acceleration
- Degradation of structure → more reproduction

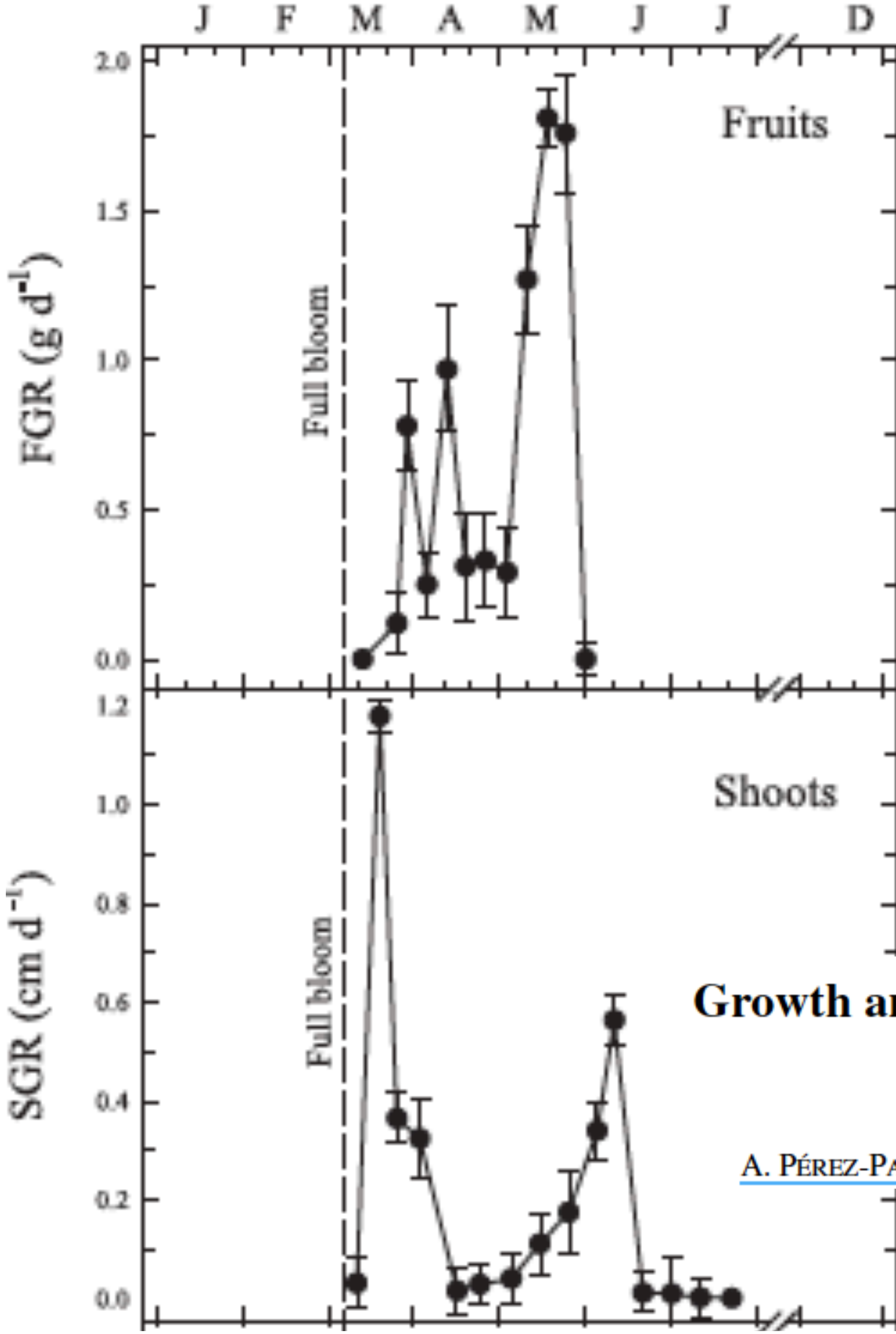
# Directions & prospects

- Connect tighter to endocrine system
  - Include impact of endocrine disruptors
- More data, more species
  - Growth and reproduction in plants
    - annual ←→ perennial plants
- Analogues
  - Regulation in symbioses
  - Virus propagation in algal blooms

**stDEB+** **dDEB**

production rate Vt $\propto \lambda$ and clearance rate Vt = 1st order





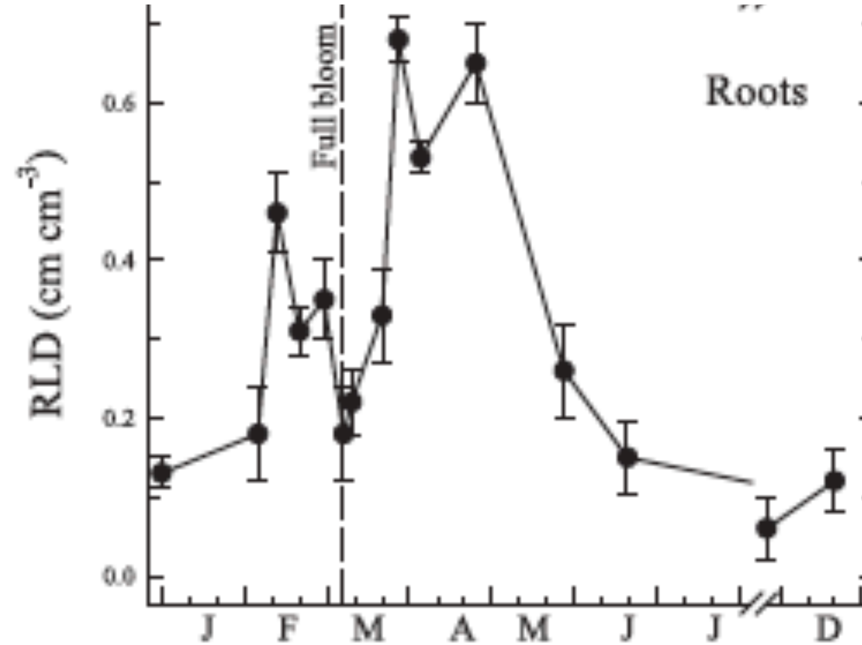




**Figure 2.** Appearance of new roots, expressed as root length density (RLD, cm cm$^{-3}$ soil), shoot growth rate (SGR, cm day$^{-1}$) and fruit growth rate (FGR, g day$^{-1}$) in Búlida apricot trees under non-limiting conditions. Full bloom 1997: 5 March, 1998: 8 March. Harvest: mid-May. Each point is the average of eight replicates ± Std.

# Growth and phenological stages of Búlida apricot trees in south-east Spain

A. Pérez-Pastor[a,c], Mª C. Ruiz-Sánchez[b,c*], R. Domingo[a,c], A. Torrecillas[a,b,c]

Agronomie 24 (2004) 93–100

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