Influence of temperature and food availability on anchovy (*Engraulis encrasicolus*) dynamics as seen through a Dynamic Energy Budget (DEB) model

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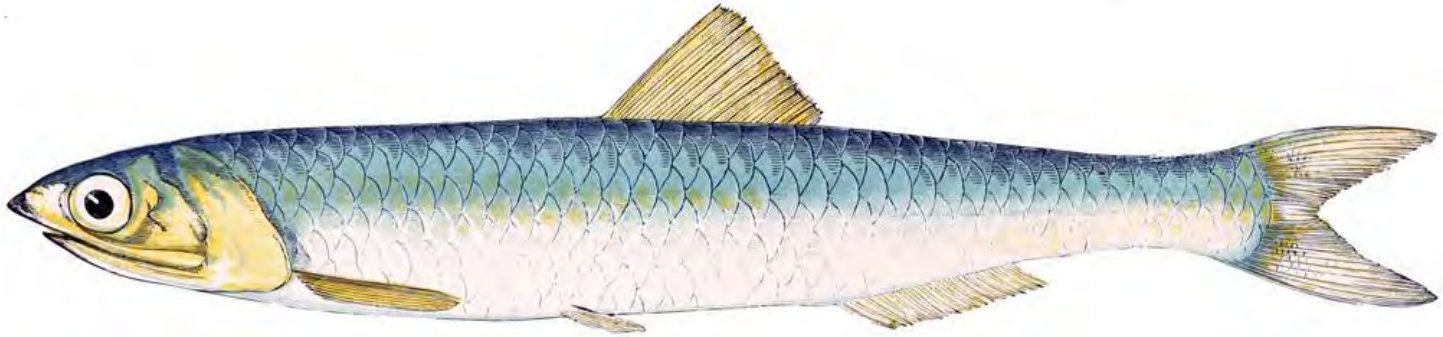
Content

- Background
- Why DEB theory
- How does DEB theory work?
- Method
  - 1) Functional response
  - 2) Temperature
  - 3) Fraction allocated to Maintenance
  - 4) Starvation
- Results
- Where do we go from here?



Background

- South Africa – three main species of small pelagic fish (Fig. 1)
  - Anchovy (*Engraulis encrasicolus*)
  - Sardine (*Sardinops sagax*)
  - Redeye Round herring (*Etrumeus whiteheadi*)
- Occupy intermediate level in marine food webs
- Short lifespan → grow fast and mature early

Fig. 1. Illustrations of a) Anchovy (Engraulis encrasicolus), b) sardine (Sadinops sagax) and c) Redeye Round herring (Etrumeus whiteheadi)

Background (cont.)

- Anchovy - target small pelagic fisheries in South Africa since mid-1960s (Fig. 2).
- Economically important → well studied
- Objective: effect of food & temperature on growth and reproduction
- Traditionally bioenergetics models → powerful tool

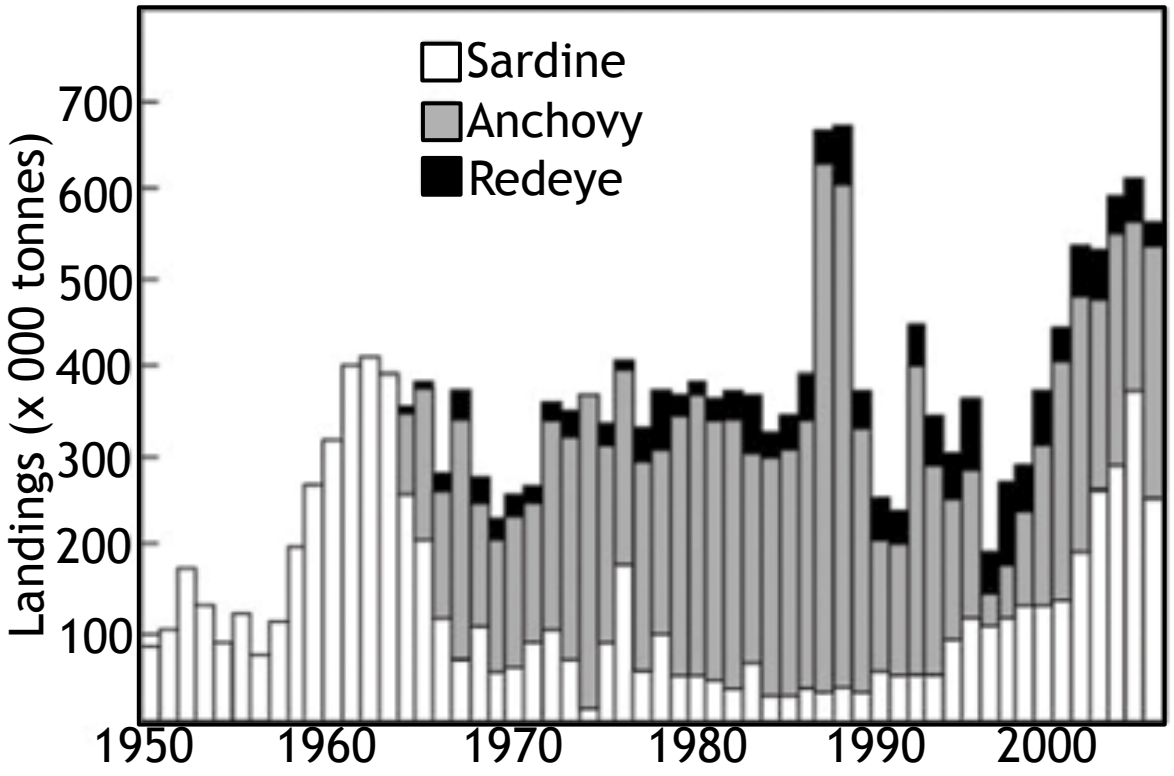


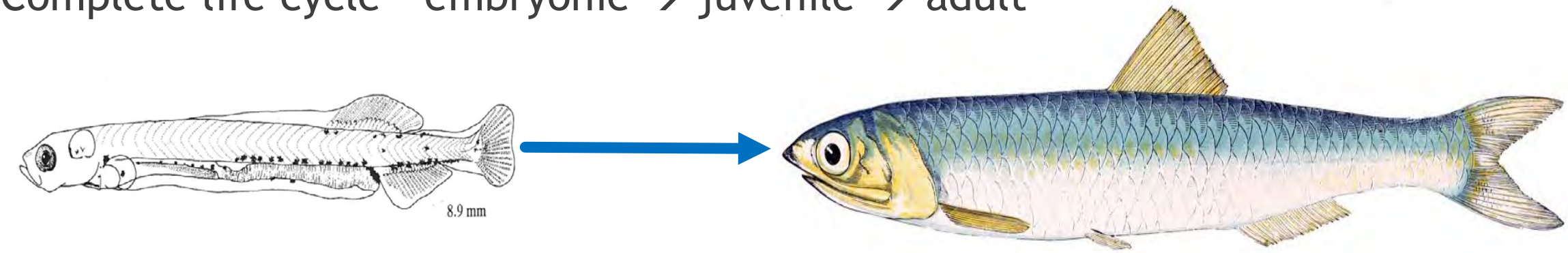
Fig. 2. Fishery data for the three small pelagic fish species caught by purse-seine fisheries for the period 1950-2005 (from Hutchings et al. 2009)

Why DEB theory?

- Kooijman(1980s) developed Dynamic Energy Budget (DEB) theory
- Model:
  - Describes
    - ✓ Rate of assimilation and energy utilization
    - ✓ Maintenance, reproduction and growth
    - ✓ As a function of environment
  - 12-parameters → predict both inter- and intraspecific variation
  - Core model → Three state variables:
    1. Energy in the reserve E (J)
    2. Volume of the structure V(cm^3)
    3. Energy allocated the reproductive buffer E_R (J)

Why DEB theory?

- Complete life cycle - embryonic → juvenile → adult



- DEB theory used to describe growth and reproduction
  - Pecquerie *et al.* (2009) → Anchovy in the Bay of Biscay
  - Pethybridge *et al.* (2013) → Anchovy in the North-western Mediterranean Sea
- DEB parameters → known

How does it work?

1) Food assimilated (p_A) → Reserve (E) → allocated to maintenance, growth & reproduction
2) Metabolism (p_C) → Somatic Maintenance (p_M) and maturity maintenance (p_J)
3) Growth (p_G) → Structure (V)
4) Reproduction (p_R) → Reproductive Reserve (ER) in adults

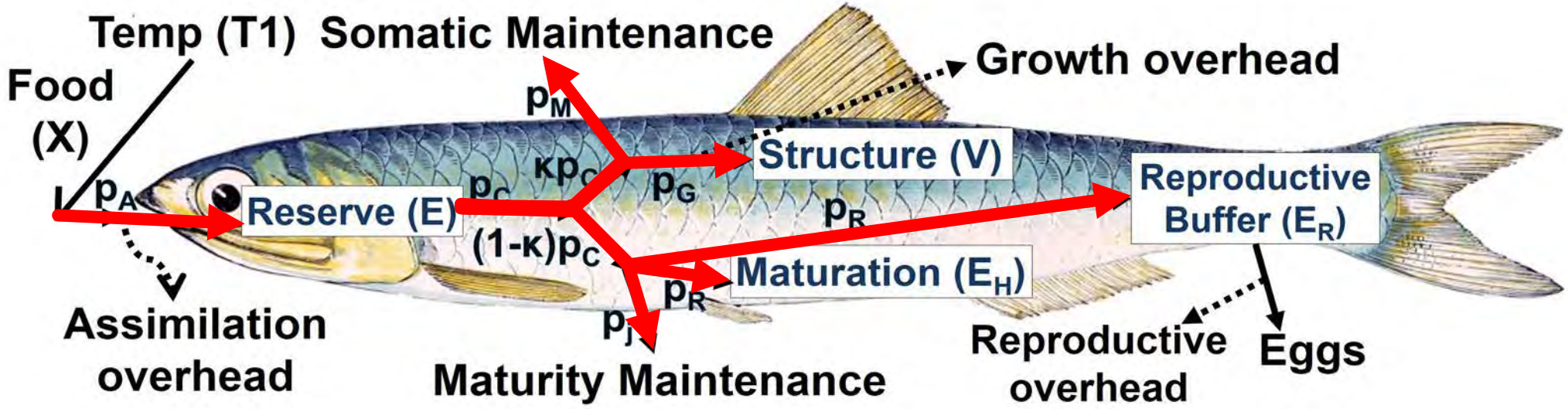


Fig. 3. A conceptual diagram of the standard Dynamic Energy Budget (DEB) showing the fluxes of an individual anchovy. During the juvenile stage the Reproductive buffer (E_R) = 0 and during the adult stage Maturation (E_H) = 0 (adapted from Pequerie *et al*. (2009)).

Methods

- ✓ Life cycle parameters → Literature
- ✓ DEB parameters → DEB tools
- ✓ Experiments
  1. Varying *f*
  2. Varying *Temperature*
  3. *Varying κ*
  4. *Starvation*

Table 1. Life cycle parameters for anchovy Engraulis encrasicolus in the Benguela based on laboratory and field data from various authors at a Reference temperature of 16ºC.

Symbol	Value	Units	Description	Author/Authors
a_b	2.28	days	Age at birth	King et al. (1978)
L_b	0.30	cm	Length at Birth	Armstrong and Thomas (1989)
a_j	60	days	Age at Metamorphosis	Armstrong and Thomas (1989)
W_{wb}	$= 0.009*(L_b^3)$	g	Wet Weight at Birth	DAFF unpublished data
L_j	3.5	cm	Length at Metamorphosis	Armstrong and Thomas (1989)
L_p	9.5	cm	Length at Puberty	Le Clus (1979)
a_m	1460	days	Life span of fish	
L_m	14.8	cm	Max Length	Waldron et al. (1989)

Experiment 1

Functional response (f)

- Ingestion rate as a function of food density

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

X = food density and kX = half saturation constant

- Constant temperature (T1)
- Values of f = 0.1, 0.3, 0.5, 0.7, 0.8, 0.9 and 1
- f = 1 → unlimited food supply
- f = 0.14 → near starvation
- Compare results to von Bertalanffy growth curve

Experiment 2

Water Temperature (*T1*)

- Temperature affects metabolism
  - Maximum assimilation rate $\{\dot{p}_{Am}\}$
  - Somatic maintenance rate $[\dot{p}_M]$
- Temp Correction:

$$c(T) = \exp\left(\frac{T_A}{T_{Ref}} - \frac{T_A}{T_1}\right)$$

$$T_A = Arrhenius\ temperature\ (9800\ K)$$
$$T_{ref} = Reference\ Temperature\ (289\ K)$$

- Values *T1* = 12 to 24ºC varying by 2ºC every time

Experiment 3

Fraction allocated to maintenance (κ)

- κ-rule
  - Fixed fraction (κ) of the reserve (E) allocated growth & maintenance.
  - Fraction (1-κ) available for development & reproduction.

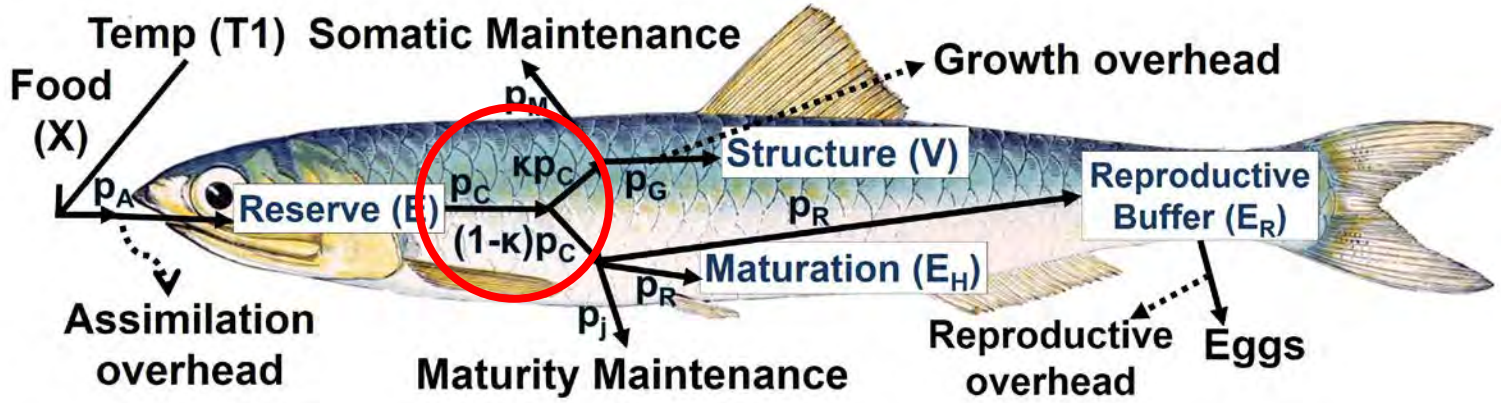


Fig. 3 A conceptual diagram of the standard Dynamic Energy Budget (DEB) (adapted from Pequerie et al. (2009)).

- For this κ = 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8
- Assumes a fixed f and $T1$

Experiment 4

Starvation study

- Once fish sexually mature $f = 0$
- Reproductive buffer (E_R) used for Maintenance
- if E_R reaches zero fish is dead
- Rerun experiment for different stages of Ovary development

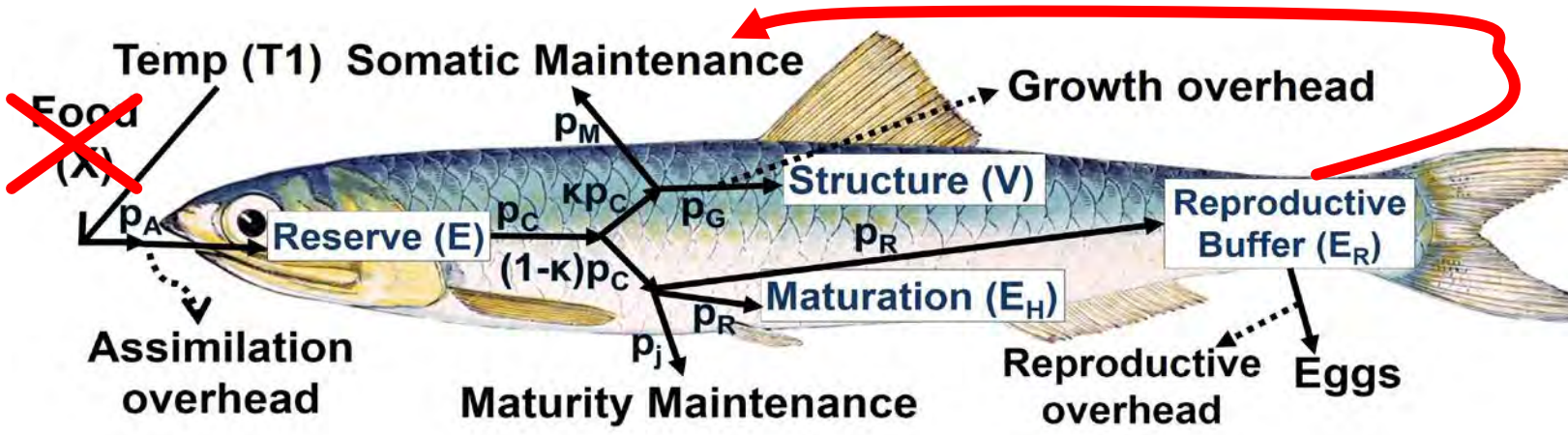


Fig. 3. A conceptual diagram of the standard Dynamic Energy Budget (DEB) (adapted from Pequerie *et al*. (2009)).

Results?

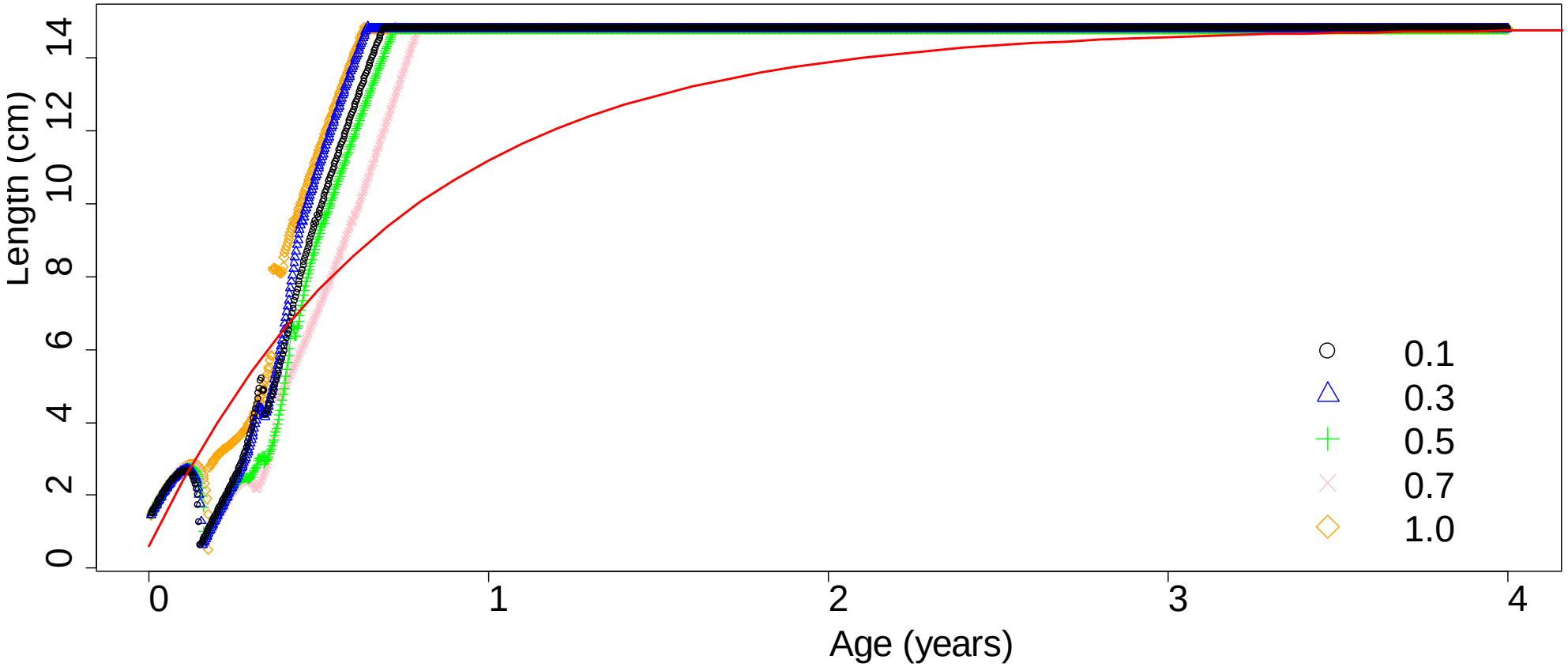


Fig. 4. The growth curves for different values of the functional response (f). f = 1 is for an unlimited food supply and f = 0.1 is near starvation. The anchovy von Bertalanffy growth curve is shown by the red line

Results?

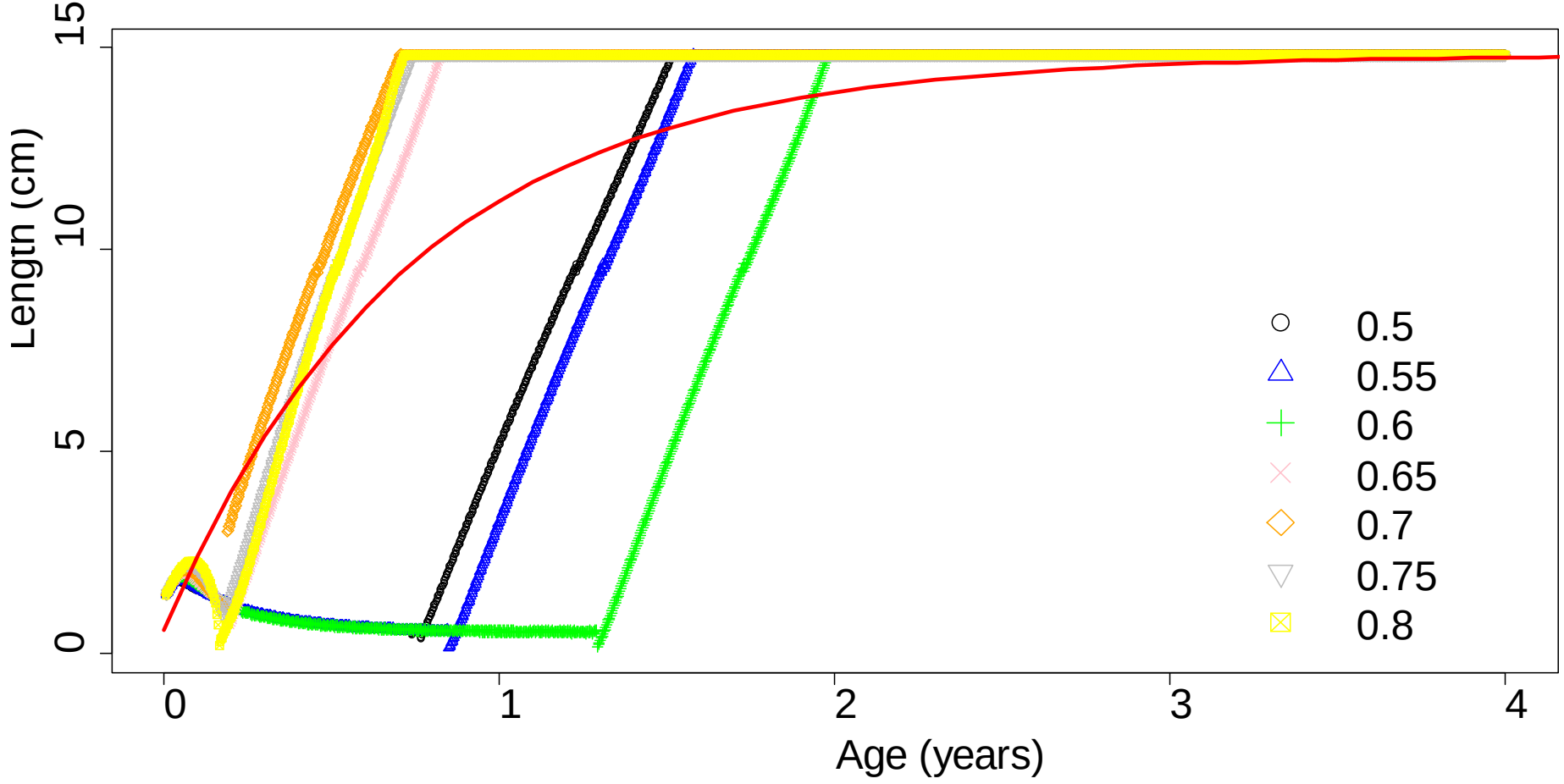
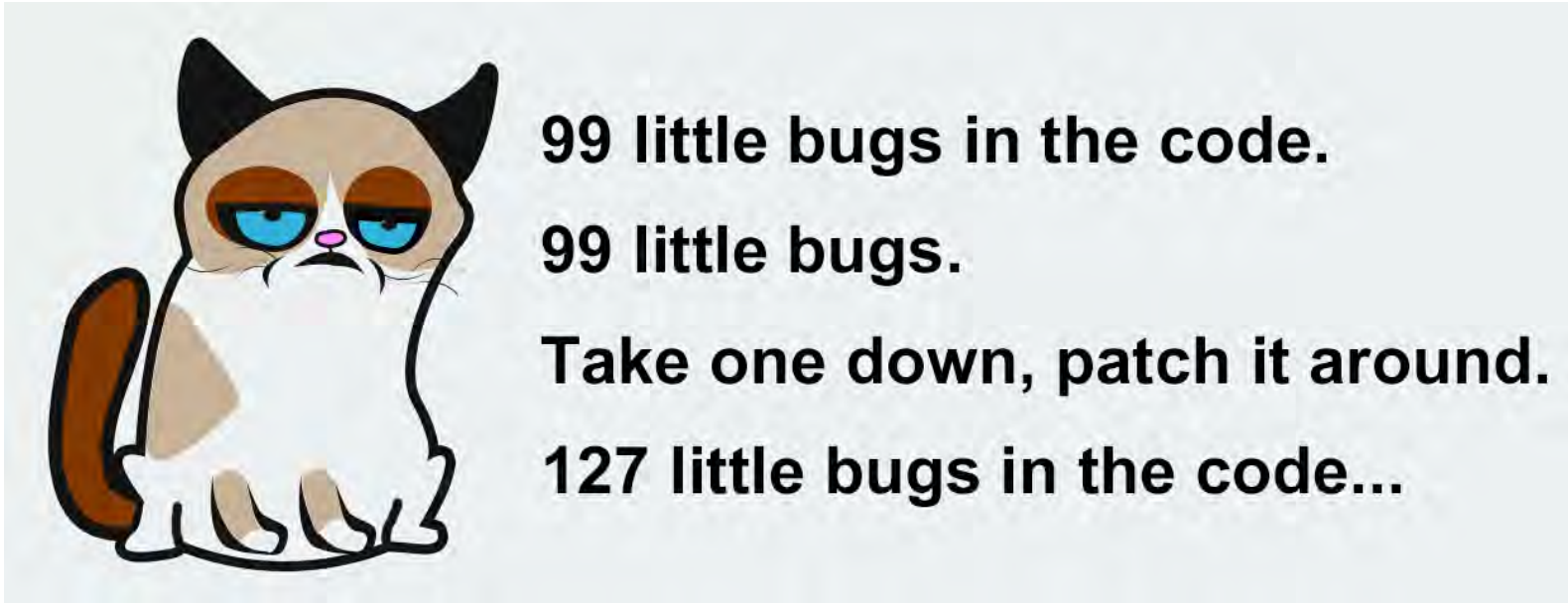


Fig. 5. The growth curves for different values of fraction allocated to maintenance (κ). The anchovy von Bertalanffy growth curve is shown by the red line

Where do we go from here?

- Debug the model for better results
- Model for:
  - Sardine (*Sardinops sagax*)
  - Redeye Round herring (*Etrumeus whiteheadi*)
- Create Varying environment
  - Food
  - Temperature
- Problems with Redeye?



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Thank You

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