Developing Small Pelagic Fish DEB (Dynamic Energy Budget) modules for IBMs in spatial population dynamics studies

Why? How? Issues/Challenges?

Laure Pecquerie

W5 - Victoria – 11 March 2017

Take-home messages

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- More data types by **designing experimental protocols together**
  - **We can only tackle this problem as a community** (experimenters, fielders and DEB modellers)
- **Otoliths are key** to improve and validate IBMs (…until we find a way to tag these fish) → Otolith data <-> **Otolith model in IBMs**

Why using DEB models in IBMs

- Full life cycle model, no discontinuity, (probably) less parameters

- Growth, Reproduction AND Development as a function of food and temperature conditions

- + other forcing functions and tracers: contaminant, parasites, $\delta^{15}N$, O_{2}, …

- Individual parameters -> multi-generation simulations, selection, eco-evo processes

Issues / Challenges?

We won't be able to include all the processes we believe are at play

- **Model structure depends on the research question**
  Ecotoxicology, Aquaculture, Ecology questions may lead to different models within the same framework

→ Spatial population dynamics – bioenergetic module for IBM module – we need the simplest model possible

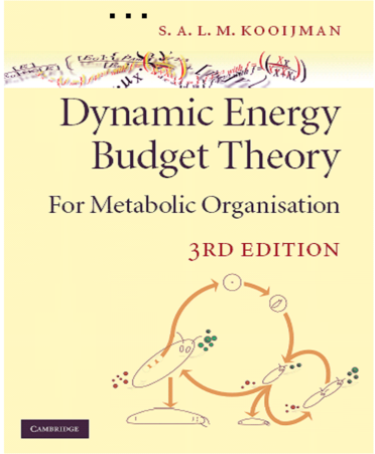
Do we need :

- Spawning dates according to environmental conditions (seasonal / interannual variability) ?
- Age at which swim bladder is functioning? (vertical migration)
- Digestion processes or constant assimilation efficiency?

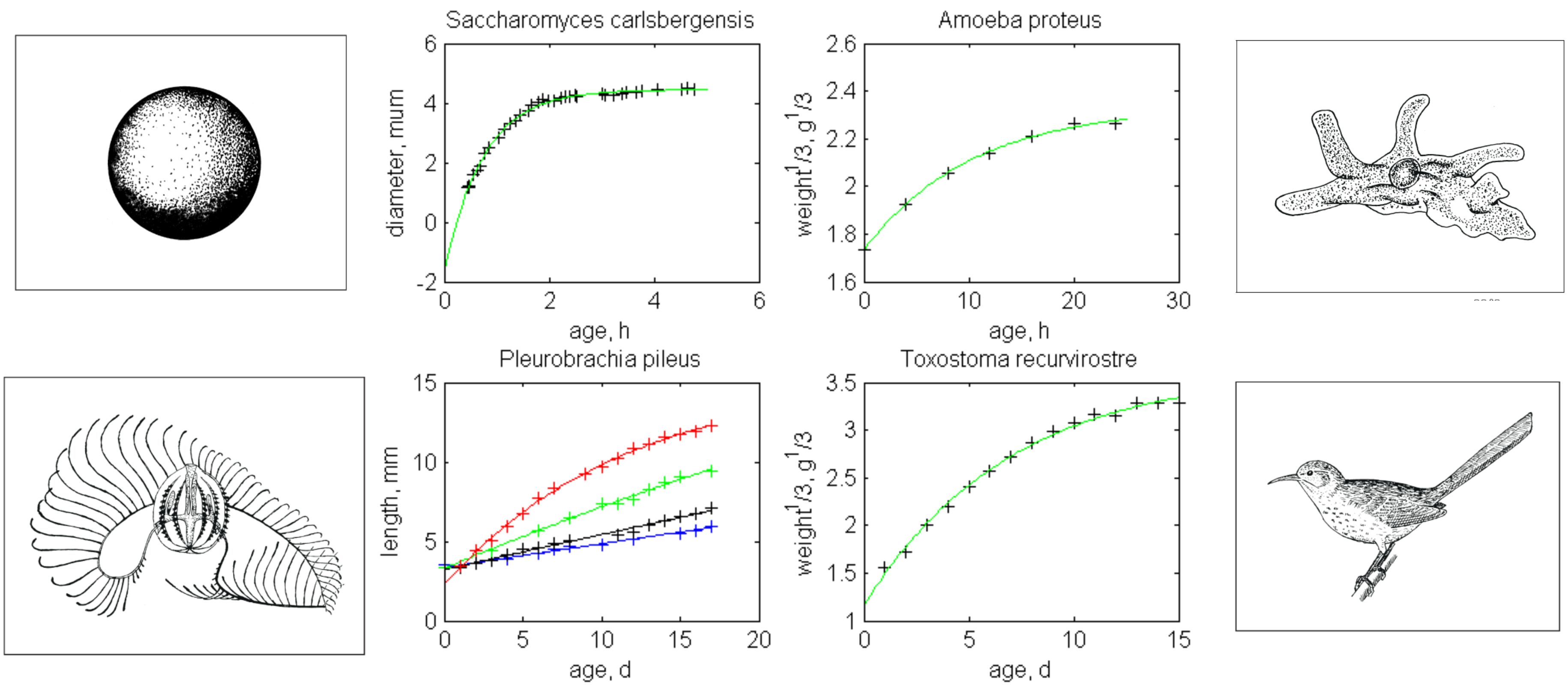
Spatial / time scales of these processes
vs
Spatial grid / time step of hydro-biogeochemical models

A bit of history

- Bas Kooijman, in 1979
- Two questions :
  - How can we quantify the effect of toxic compounds on Daphnia reproduction?
  - Which effect has a small decrease in individual reproduction on the dynamics of the population?

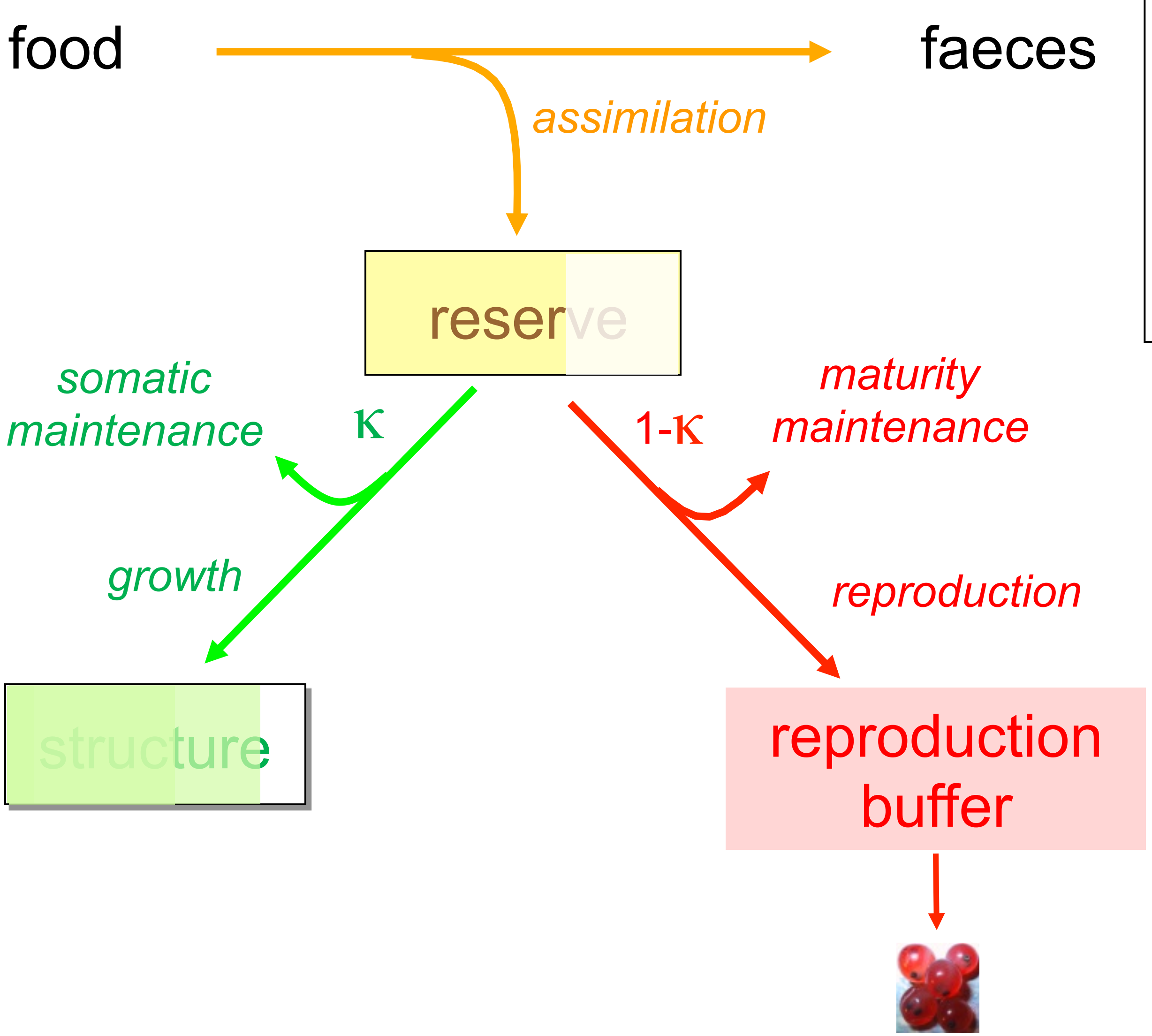


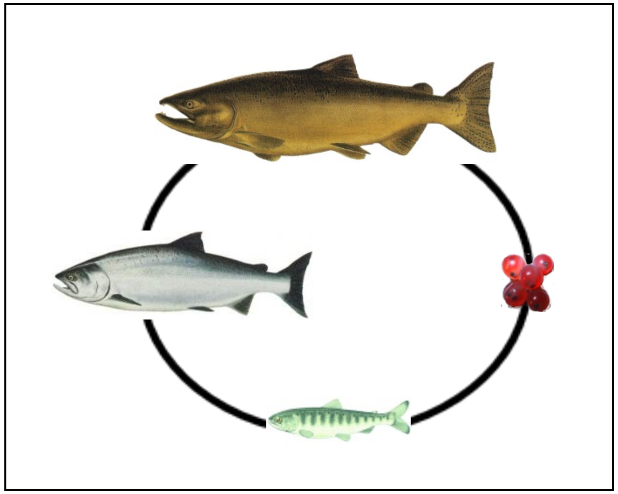
Observations : Asymptotic growth



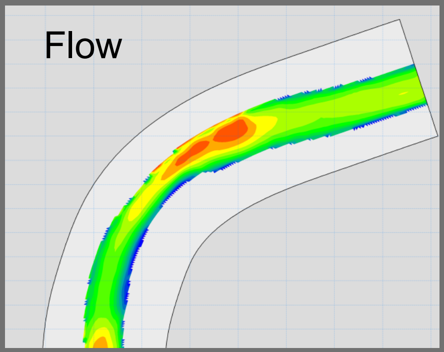
Kooijman, 2010

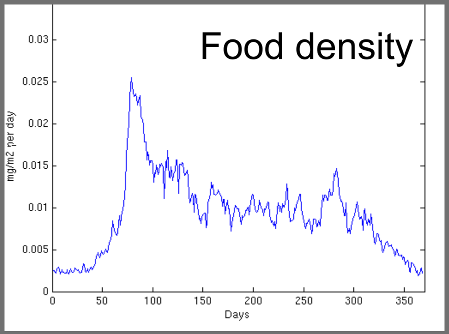
Life events in a standard DEB model

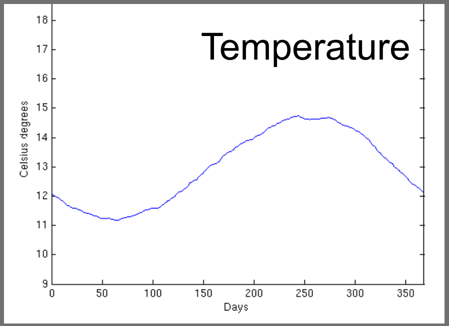


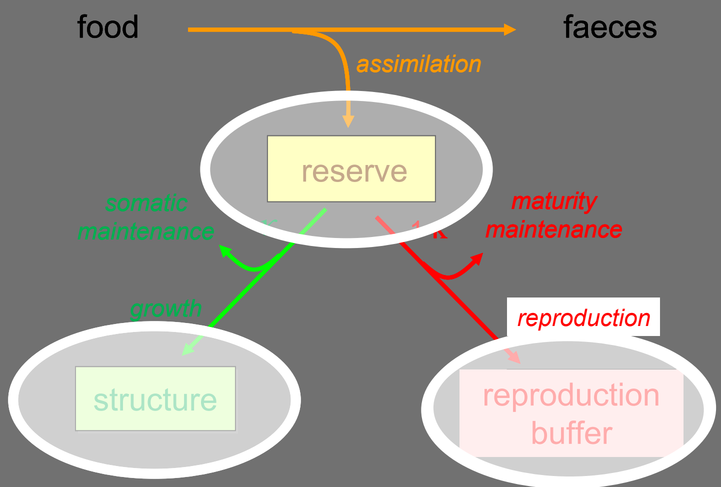


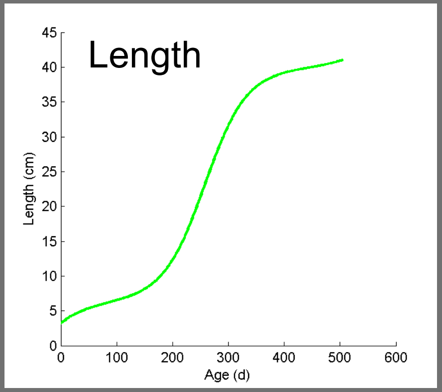
Model simulations

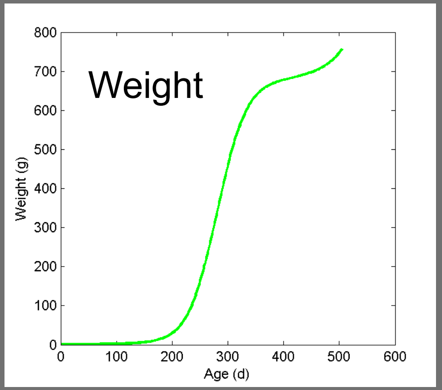


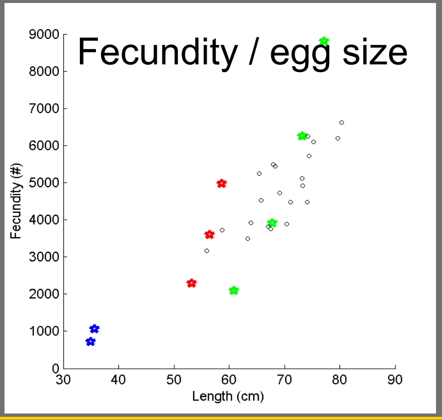








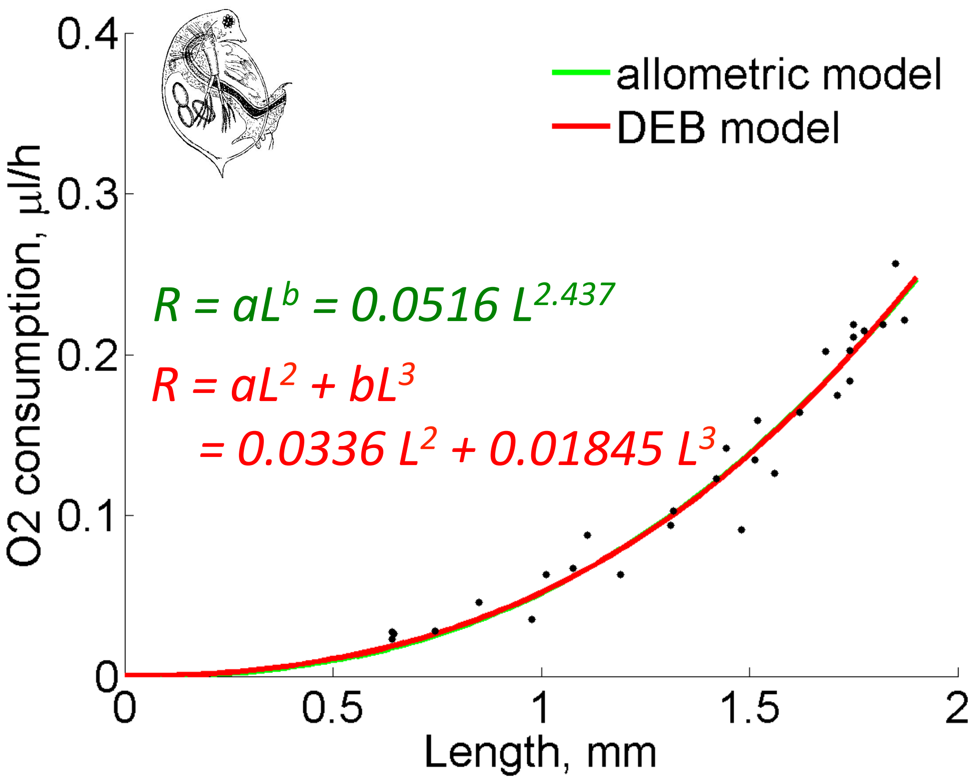


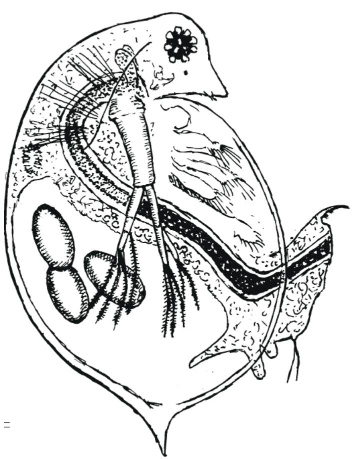


INPUTS DEB MODEL OUTPUTS

Modelling approach

- Oxygen consumption
  - Empirical → $R = aL^b$
    Theoretical → $R = aL^2 + bL^3$ (Kooijman, 2000)

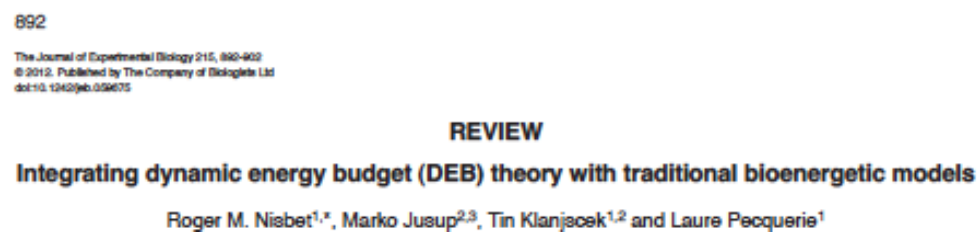




Daphnia pulex
d'après Kooijman (2000)

Issues / Challenges?

- State variables do not correspond to observables/data
- DEB and traditional bioenergetic models have different emphases / processes, thus different data needs for calibration
  (but ways to link them)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REVIEW

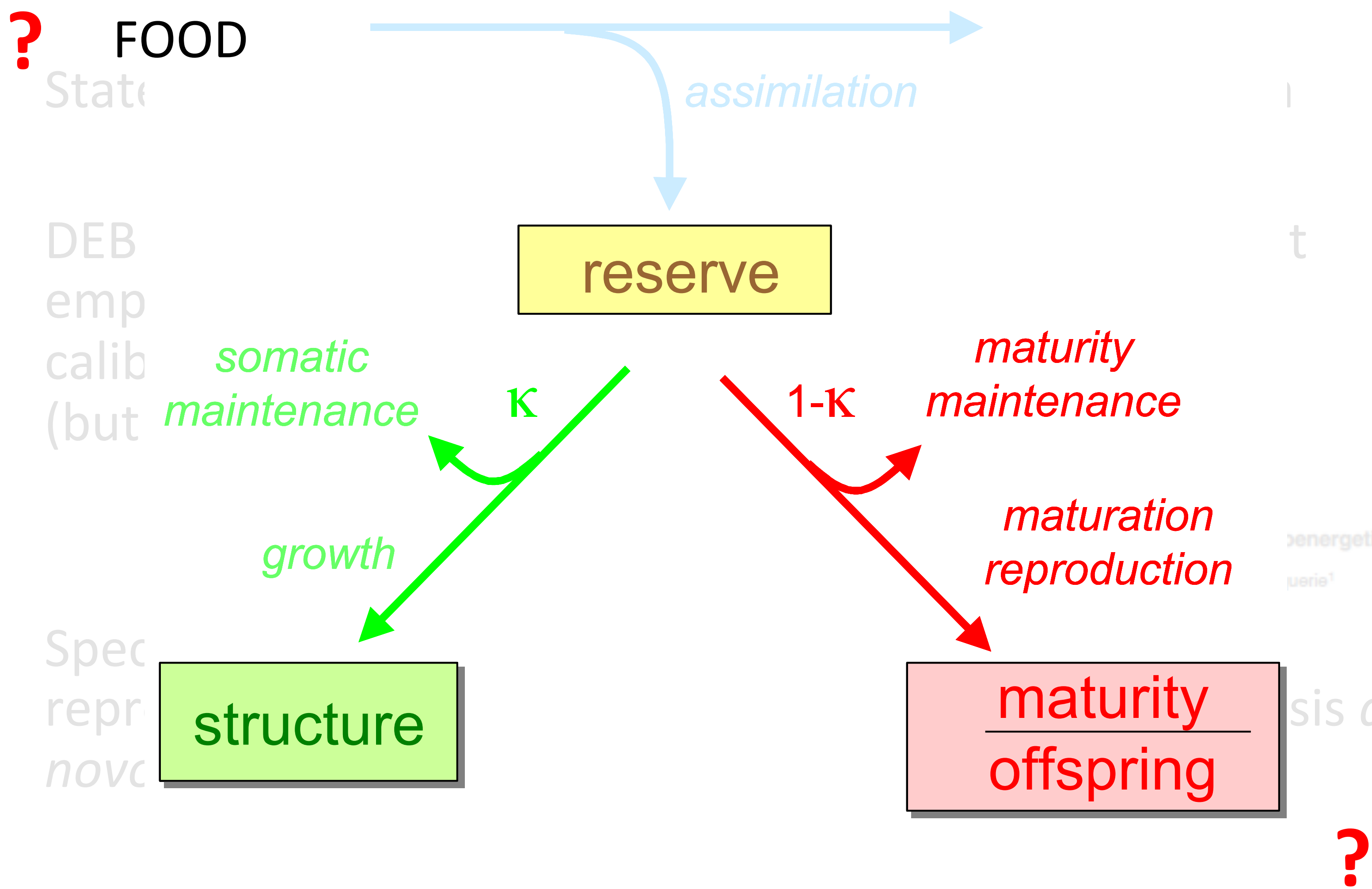
Integrating dynamic energy budget (DEB) theory with traditional bioenergetic models

Roger M. Nisbet[1,*], Marko Jusup[2,3], Tin Klanjscek[1,2] and Laure Pecquerie[1]

- Specific to SPF: we hardly observe feeding and full reproduction investment (batch spawner / vitellogenesis *de novo*)

→ Several parameter sets provide similar fits

Issues / Challenges?



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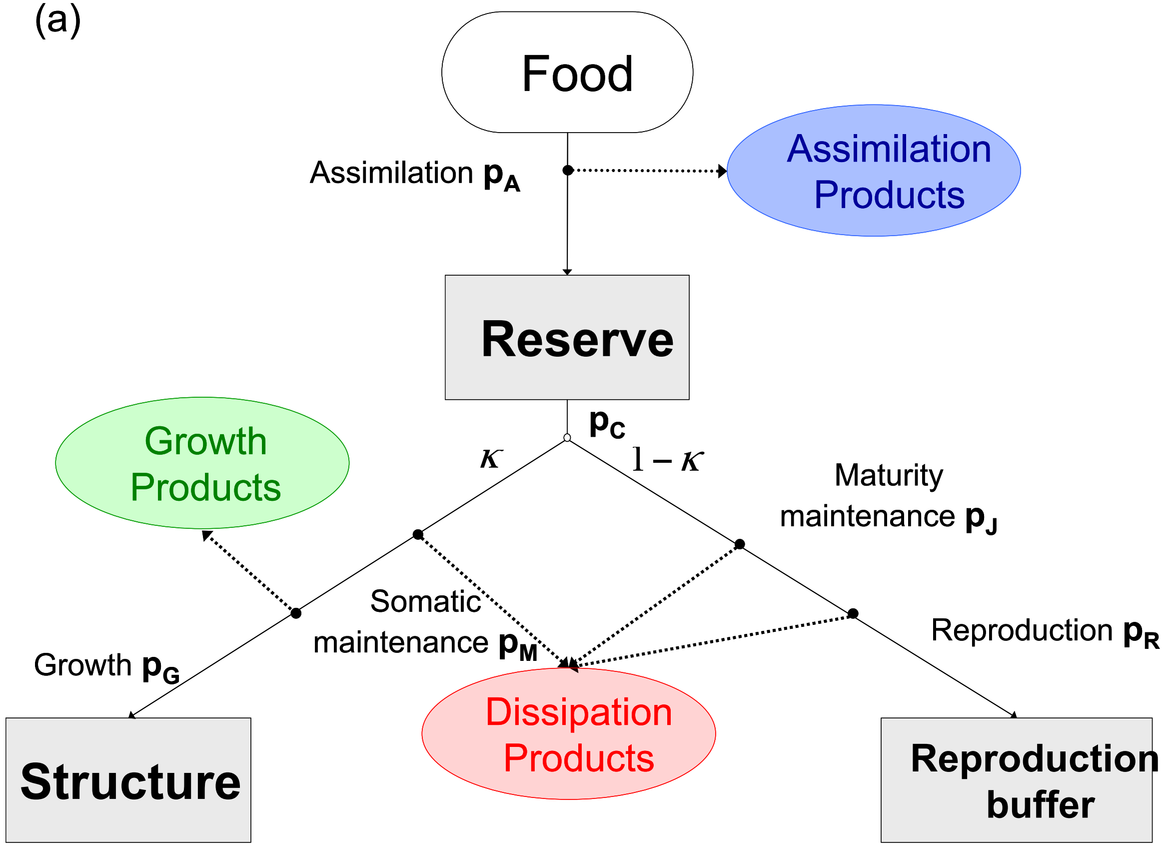
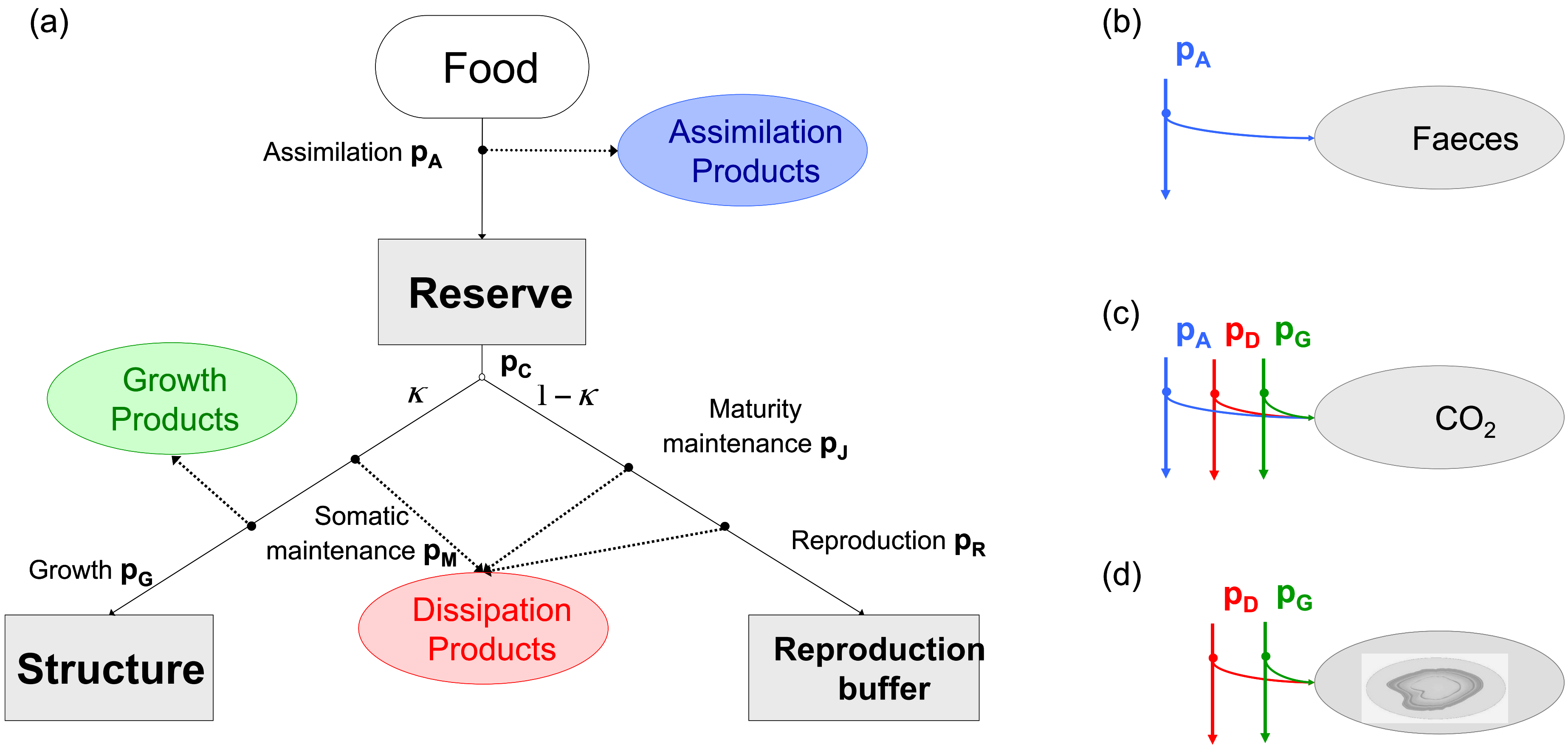
metabolic products in DEB models

(a)



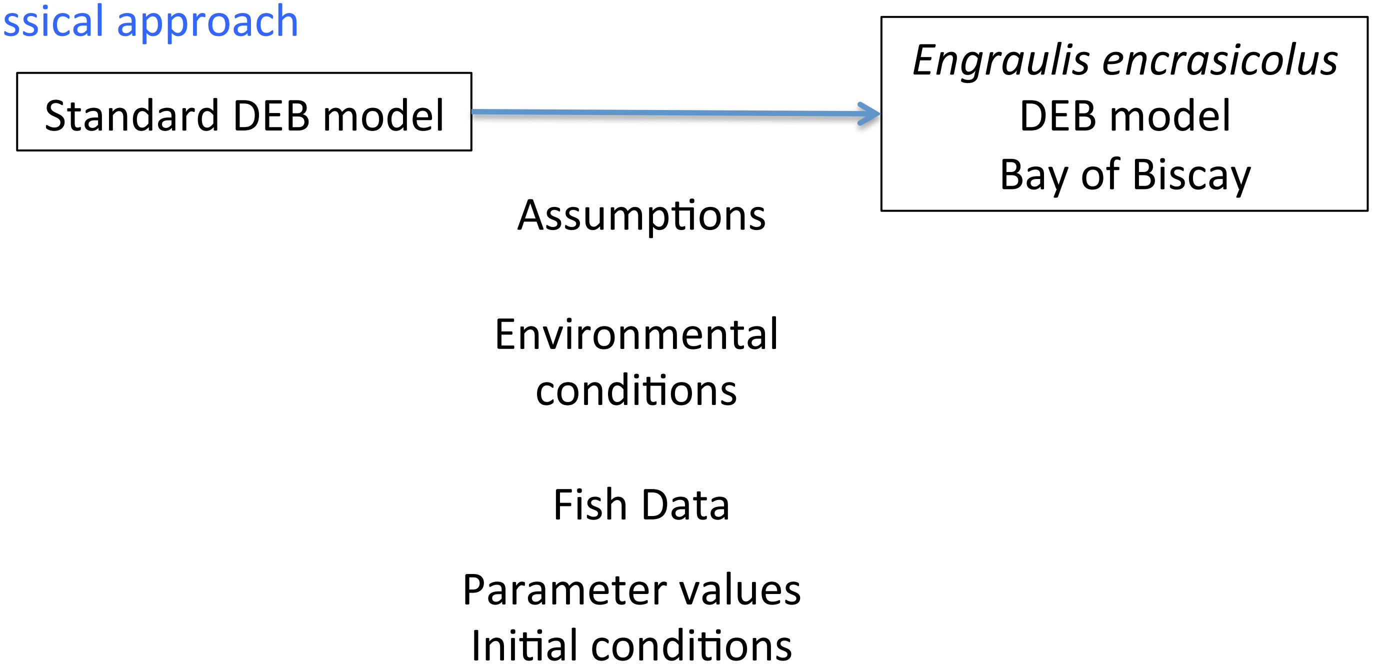
Biocarbonate = metabolic product



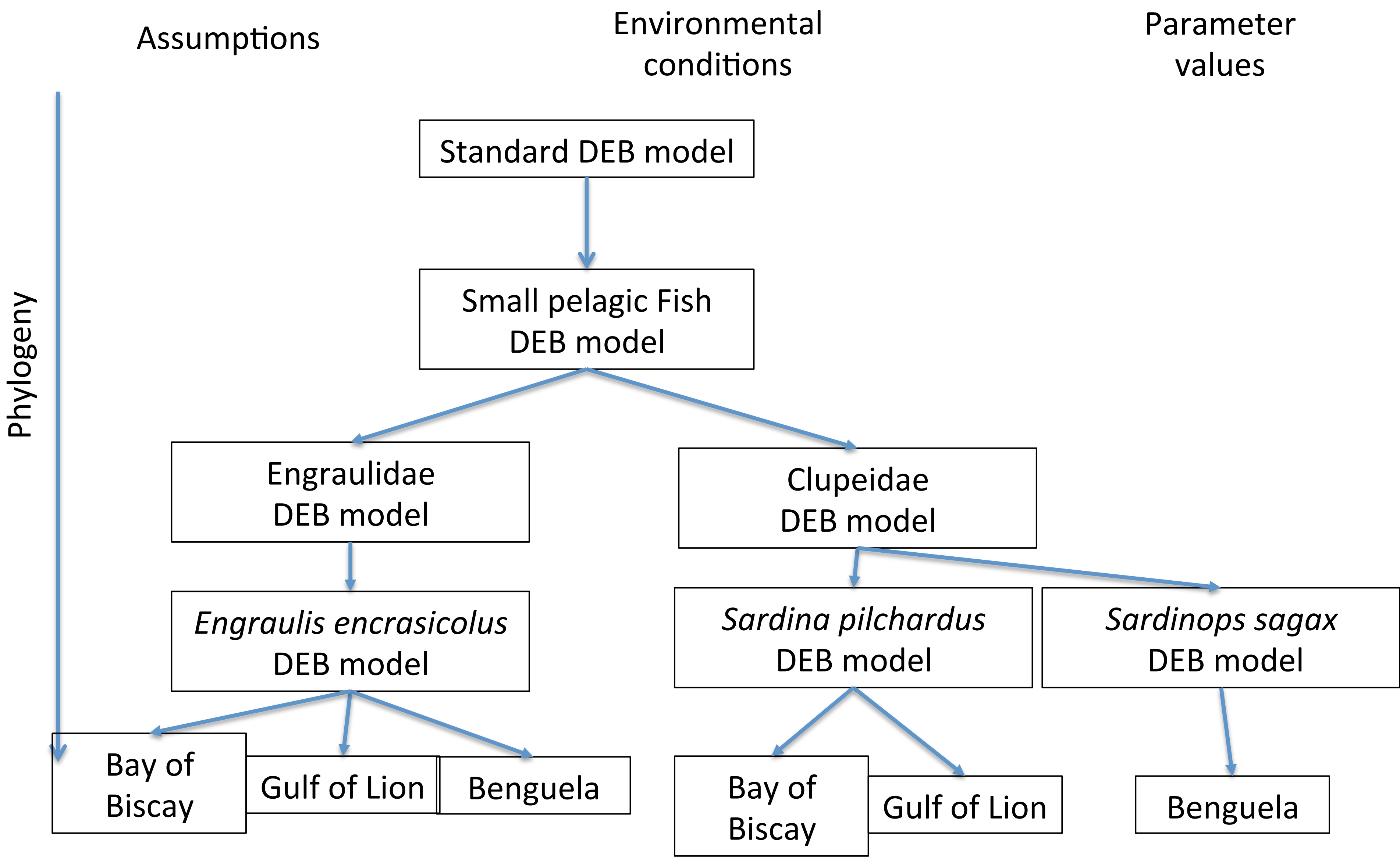
How to go beyond?

- Taking into account phylogeny in DEB parameter estimation for small pelagic fish will reduce uncertainty in parameter estimates.
- **Multi-spcies estimation procedure** under development

Classical approach



New approach



Amp Collection : currently 600 entries

Species list: taxonomic view

phylum	class	order	family	species	common name	type	MRE	SMSE	complete	data
Porifera	Demospongiae	Haplosclerida	Chalinidae	Haliclona oculata	Mermaid's glove	std	0.022	0.039	2.3	am Wwb Wwp Ri t-Ww
Cnidaria	Cubozoa	Chirodropida	Chirodropidae	Chironex fleckeri	Sea wasp	abj	0.152	0.262	2	ap Lb Lp Li Wi Ri t-L
Cnidaria	Hydrozoa	Anthomedusae	Hydridae	Hydra viridissima	Green hydra	stf	0.069	0.063	2.5	ab ap Vb Vp Vi Ri t-V t-N
Cnidaria	Scyphozoa	Semaeostomeae	Pelagiidae	Pelagia noctiluca	Mauve stinger	abj	0.230	0.304	3	L0 Lb Lp ap am Li Wdi Ri RQ L-Ww L-Wd L-WN L-WC t-Ww LR T-ab T-JO T-JN
Ctenophora	Tentaculata	Lobata	Bolinopsidae	Mnemiopsis leidyi	Sea walnut	asj	0.303	0.356	3	ab ap am Lb Lj Lp Li Wd0 Wwi Ri t-L t-N L-Ww L-Wc L-V L-R L-R Ww-R
Ctenophora	Tentaculata	Lobata	Bolinopsidae	Bolinopsis mikado	Japanese comb jelly	abj	0.220	0.343	2.5	am L0 Lj Lp Li WC0 WN0 Wwp Wdi Ri L-Wd L-Ww Wd-JO Wd-JN T-R
Ctenophora	Tentaculata	Cydippida	Mertensiidae	Callianira antarctica	Antarctic comb jelly	abj	0.326	0.490	1	Li Wdi L-Wd L-WC L-WN Wd-JO Wd-JN
Ctenophora	Tentaculata	Cydippida	Pleurobrachiidae	Pleurobrachia pileus	Sea gooseberry	abj	0.139	0.174	3	ab am Lb Lp Li Wdi Ri RQ t-L_T L-F Ww-JO_T
Ctenophora	Tentaculata	Cydippida	Pleurobrachiidae	Pleurobrachia bachei	Sea gooseberry	abj	0.183	0.241	5	ab ap Lb Lp Li Wd0 Wdi Ri t-L_X L-N_X L-JO_T L-Wd
Ctenophora	Nuda	Beroida	Beroidae	Beroe gracilis	Melon comb jelly	abj	0.219	0.262	3	ab ap am Lb Li Wwi t-L L-Ww Ww-JO
Ctenophora	Nuda	Beroida	Beroidae	Beroe ovata	Comb jelly	abj	0.289	0.506	2	L0 Lb Lp Li Wd0 Wwi Ri Wd-JO Ww-R_X t-Ww t-Wc L-Ww Ww-JO_T
Chaetognatha	Sagittoidea	Aphragmophora	Sagittidae	Sagitta hispida	Arrow worm	abj	0.096	0.158	2.5	ah ab ap am Lh Lb Lp Li Ri JX t-L t-Wd
Acanthocephala	Archiacanthocephala	Moniliformida	Moniliformis	Moniliformis dubius	Worm	std	0.214	0.208	2	ap am Li Wwi GSI t-M_N t-M_DNA t-M_RNA
Rotifera	Monogononta	Ploimida	Asplanchnidae	Asplanchna girodi	Rotifer	std	0.157	0.142	3.5	Vb t-V_f X-ap X-am X-Vp X-Vi X-Ri
Rotifera	Monogononta	Ploimida	Brachionidae	Brachionus plicatilis	Rotifer	std	0.288	0.407	2.5	ab ap am Wwb Wwp Wwi Ri JCi JXi K
Gastrotricha	Gastrotricha	Chaetonotida	Chaetonotidae	Aspidiophorus polystictos	Hairyback	std	0.019	0.021	2.3	ab ap am Lb L_t Li Wwb Wwi Ri
Platyhelminthes	Turbellaria	Tricladida	Dugesiidae	Schmidtea polychroa	Freshwater flatworm	abj	0.033	0.033	2	ab ap_T am Lb Lp Li Wdb Wdp Wdi Ri
Brachiopoda	Rhynchonellata	Terebratulida	Terebratellidae	Magellania fragilis	Brachiopod	std	0.037	0.057	1.2	ab ap am Lb Lp Li Ri L-Wd t-L
Phoronida	Phoronida	Phoronida	Phoronidae	Phoronis pallida	Horseshoe worm	std	0.065	0.078	1	ab am Lb Lp Li Wwi Ri t-L
Bryozoa	Gymnolaemata	Cheilostomata	Flustridae	Flustra foliacea	Broad-leaved hornwrack	std	0.017	0.022	1.5	ap am Li t-L t-Wd
Annelida	Polychaeta	Scolecida	Capitellidae	Capitella teleta	Worm	std	0.061	0.050	1.5	am Li t-L t-N
Annelida	Polychaeta	Capitellida	Arenicolidae	Arenicola marina	Lugworm	std	0.433	0.453	2.5	ab ap am Lb Lp Li Wdb Wdp Wdi rB Ri t-Wd
Annelida	Clitellata	Haplotaxida	Lumbricidae	Dendrobaena octaedra	Earth worm	std	0.164	0.305	1.8	ab ap am Lb Lp Li Wwb Wwp Wwi Ri t-Ww
Annelida	Clitellata	Haplotaxida	Lumbricidae	Lumbricus terrestris	Common earthworm	std	0.090	0.073	2.5	ab ap am Li Wwb Wwp Wwi t-Ww t-N
Annelida	Clitellata	Haplotaxida	Lumbricidae	Octolasion cyaneum	Earthworm	std	0.111	0.104	2.5	ab ap am Li Wwb Wwp Wwi t-Ww t-N
Annelida	Clitellata	Haplotaxida	Lumbricidae	Aporrectodea longa	Black-headed worm	std	0.089	0.076	2.5	ab ap am Li Wwb Wwp Wwi t-Ww t-N
Annelida	Clitellata	Haplotaxida	Lumbricidae	Eisenia fetida	Redworm	std	0.148	0.153	2.5	ab ap am Lb Lp Li Wwb Wwp Wwi Ri t-Ww
Mollusca	Polyplacophora	Neoloricata	Ischnochitonidae	Lepidochitona cinerea	Common chiton	abj	0.042	0.044	2.8	ap am Lp Li Ww_b Ww_j Wd_L Ri t-L
Mollusca	Bivalvia	Veneroida	Cardiidae	Cerastoderma edule	Common cockle	abj	0.045	0.054	2.5	ab ap am Lb Lp Li Wdp Wdi rB Ri
Mollusca	Bivalvia	Veneroida	Cardiidae	Cerastoderma glaucum	Lagoon cockle	abj	0.020	0.024	2.5	ab ap am Lb Lp Li Wdp Wdi rB Ri t-L
Mollusca	Bivalvia	Myoida	Myidae	Mya arenaria	Soft-shell clam	abj	0.346	0.256	2.8	ab ap am Lb Lp Li Wdp Wdi rB Ri t-L L-Ww t-Wd t-WdR
Mollusca	Bivalvia	Veneroida	Tellinidae	Macoma balthica	Baltic macoma	abj	0.172	0.274	2.2	ab ap am Lb Lp Li Wdp Wdi rB RL t-L
Mollusca	Bivalvia	Veneroida	Solenidae	Ensis directus	Atlantic jackknife clam	abj	0.242	0.250	3.5	ab aj ap am Lb Lj Lp Li Wdp Wdi GSI Fm t-L L-Ww L-F L-JO
Mollusca	Bivalvia	Veneroidea	Veneridae	Ruditapes philippinarum	Manila clam	abj	0.117	0.117	2.2	ab ap am Lb Lp Li Wdb Wdp Wdi Ri t-L
Mollusca	Bivalvia	Unionoida	Unionidae	Echyridella menziesii	New Zealand freshwater mussel	abj	0.015	0.021	2.3	am Lp Li Wwb Wd_L Ri t-L
Mollusca	Bivalvia	Unionoida	Unionidae	Anadonta cygnea	Swan mussel	abj	0.082	0.095	2	ap am Li Wwb Ri t-L L-Ww L-Wd
Mollusca	Bivalvia	Unionoida	Hyriidae	Westralunio carteri	Carter's freshwater mussel	abj	0.045	0.050	2	ap am Lp Li Wwb Wwi Ri t-L
Mollusca	Bivalvia	Veneroida	Arcticidae	Arctica islandica	Ocean quahog	abj	0.146	0.130	2.5	ab aj ap am Lb Lj Lp Li Wdp Ri t-L L-W

http://www.bio.vu.nl/thb/deb/deblab/add_my_pet/species_list.html

Small pelagic fish entries : 6

ONTEXT	COLLECTION	WIKI				
	notopterus	featherback				
Arapaimidae	Arapaima gigas	Pirarucu	std	0.095	0.100	2.5
Hiodontidae	Hiodon tergisus	Mooneye	std	0.026	0.033	2
Clupeidae	Sardina pilchardus	European pilchard	abj	0.086	0.091	2.5
Clupeidae	Sardinella aurita	Round sardinella	abj	0.101	0.096	2.5
Clupeidae	Sprattus sprattus	Sprat	abj	0.180	0.311	2.5
Clupeidae	Clupea harengus	Atlantic herring	abj	0.079	0.079	2.7
Clupeidae	Alosa sapidissima	American shad	abj	0.163	0.141	2.5
Engraulidae	Engraulis encrasicolus	European anchovy	abj	0.256	0.351	2.7
Chirocentridae	Chirocentrus dorab	Dorab wolf herring	abj	0.107	0.138	2.5

Atlantic herring entry

CONTEXT COLLECTION WIKI

Clupea harengus (Atlantic herring):

Results Code

Predictions & Data

Model: abj

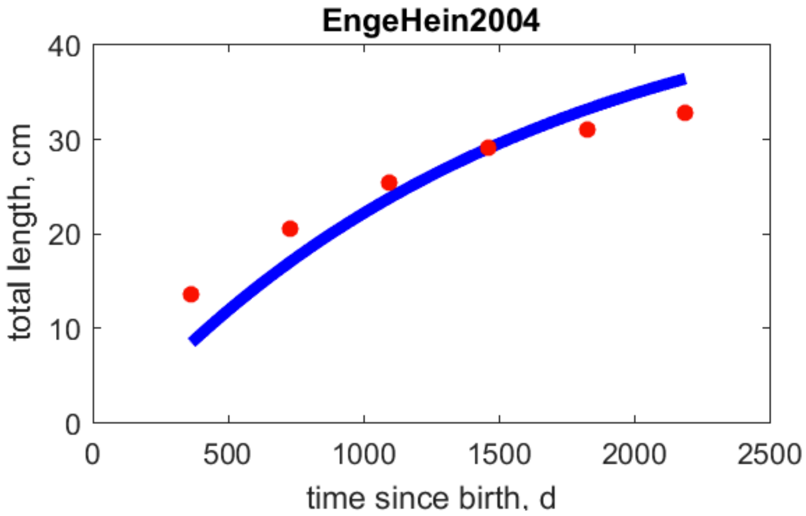
COMPLETE = 2.7
MRE = 0.079
SMSE = 0.079

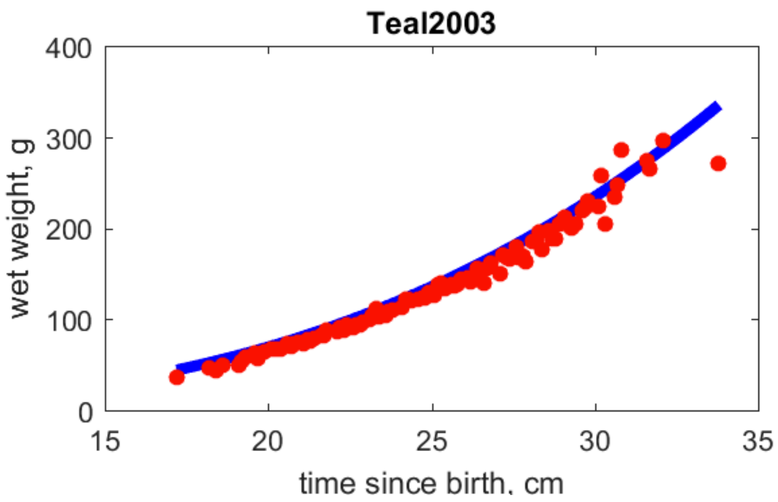
Zero-variate data						
Data	**Observed**	**Predicted**	**(RE)**	**Unit**	**Description**	**Reference**
ab	27	28.55	(0.05726)	d	age at birth	Geff2002
aj	177	172.7	(0.02418)	d	age at metam	Blax1968
ap	1460	1338	(0.08331)	d	age at puberty	EngeHein2004
am	8030	8018	(0.001482)	d	life span	fishbase, Lea1930
Lb	1.1	1.056	(0.03971)	cm	total length at birth	Geff2002
Lp	29	34.15	(0.1775)	cm	total length at puberty	EngeHein2004
Li	45	48.18	(0.07061)	cm	ultimate total length	fishbase, BigeBrad1963
Wi	1050	970.7	(0.07548)	g	ultimate wet weight	fishbase, Koli1990
Ri	54.79	54.65	(0.002694)	#/d	maximum reprod rate	fishbase

Uni-variate data					
Dataset	**Figure**	**(RE)**	**Independent variable**	**Dependent variable**	**Reference**
tL	see Fig. 1	(0.09636)	time since birth	total length	Teal2003
tL_N	see Fig. 2	(0.1063)	time since birth	total length	EngeHein2004
tW	see Fig. 3	(0.2227)	time since birth	wet weight	Teal2003
LW	see Fig. 4	(0.06919)	time since birth	wet weight	Teal2003

Pseudo-data

Atlantic herring entry





How to go beyond?

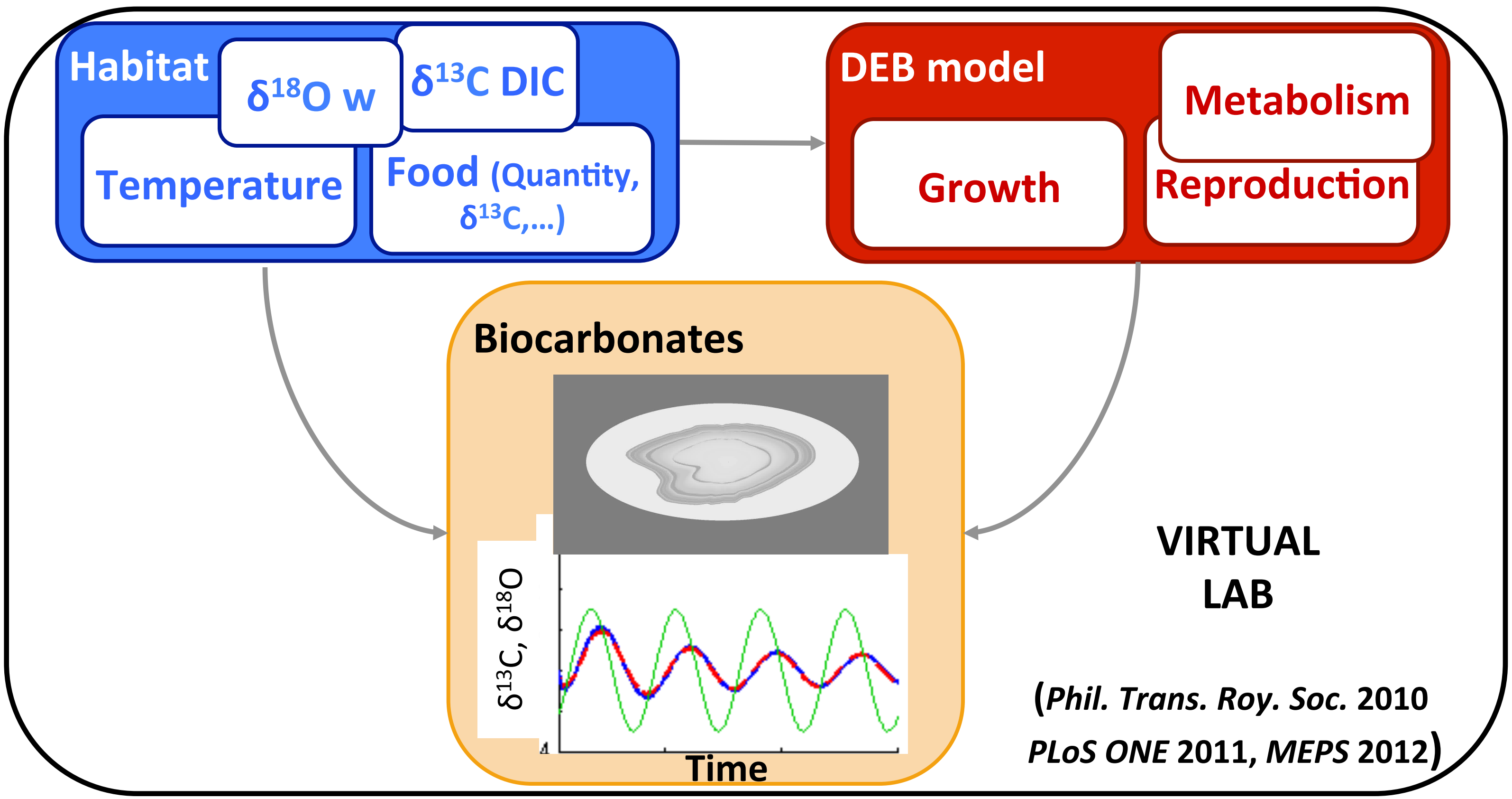
- Taking into account phylogeny in DEB parameter estimation for small pelagic fish will reduce uncertainty in parameter estimates.
- **Multi-spcies estimation procedure** under development

- Modelling otolith growth, opacity, $\delta^{18}O$, $\delta^{13}C$ in IBMs

Why modelling otolith formation?

➔ **To embrace and take advantage of these multi-factor interactions to improve our interpretation and use of these unique archives**

A) Calibration of proxies	B) Life history reconstruction	C) Environmental scenario studies (2D, 3D models)
Understand	*Improve*	*Predict*



Otolith modeling : individual history