Larval Fish Physiology & Individual-based Models:
Exploring Climate Impacts on Early Life Stages of Key Species

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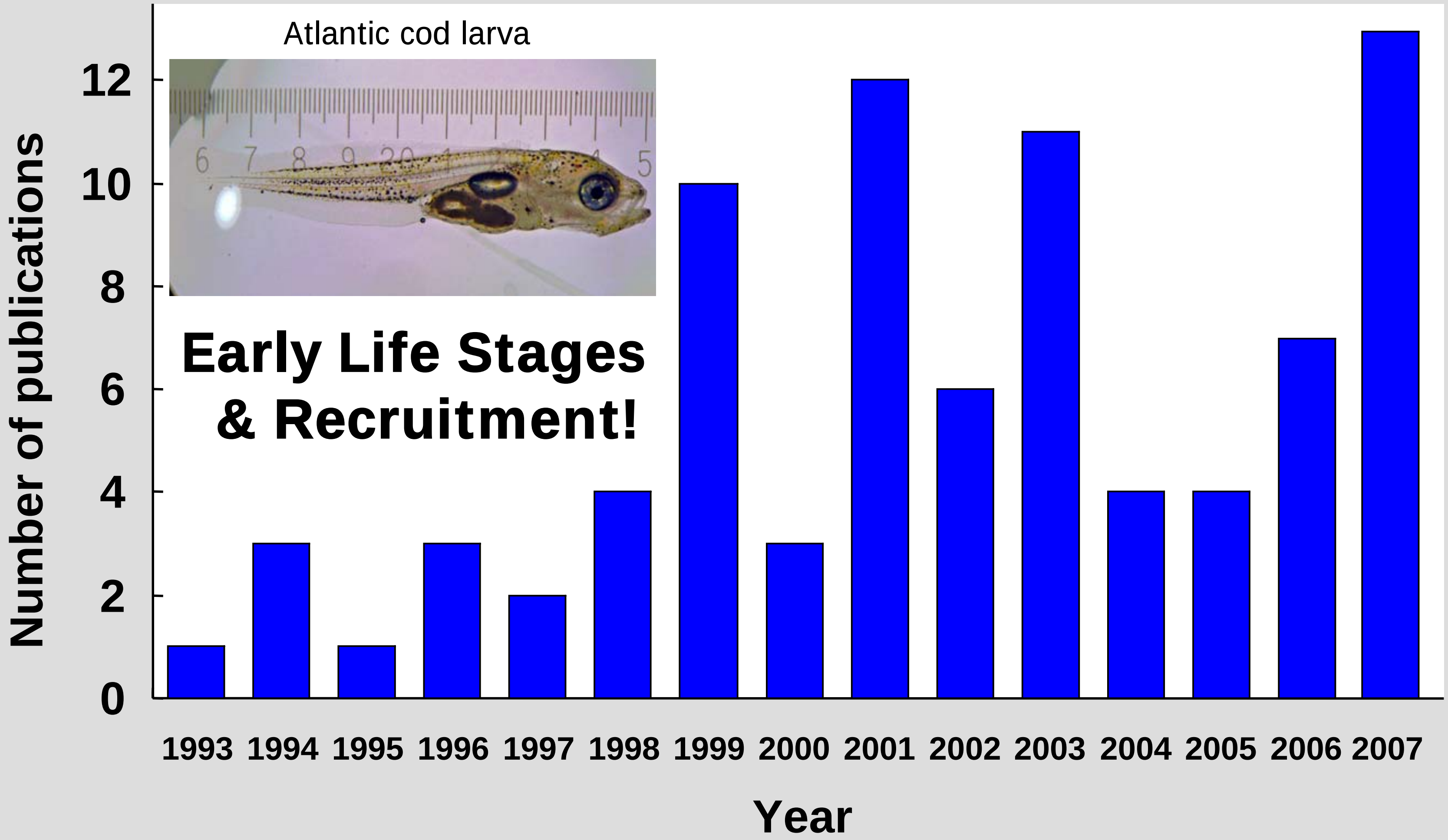
Coupled physical – biological IBMs for marine fish larvae



IBMs allow individuals to have unique characteristics – in the case of pelagic eggs & larvae - environmental conditions in time & space

(updated from Tom Miller 2006, WKAMF)

coupled physical-biological model system

egg & larval IBM parameterization

Part I

endogenous feeding stages

development of eggs & yolksac larvae

Temperature

Part II

exogenously feeding stages

rates of energy loss & gain by larvae

Temperature

Part III model application (North Sea)

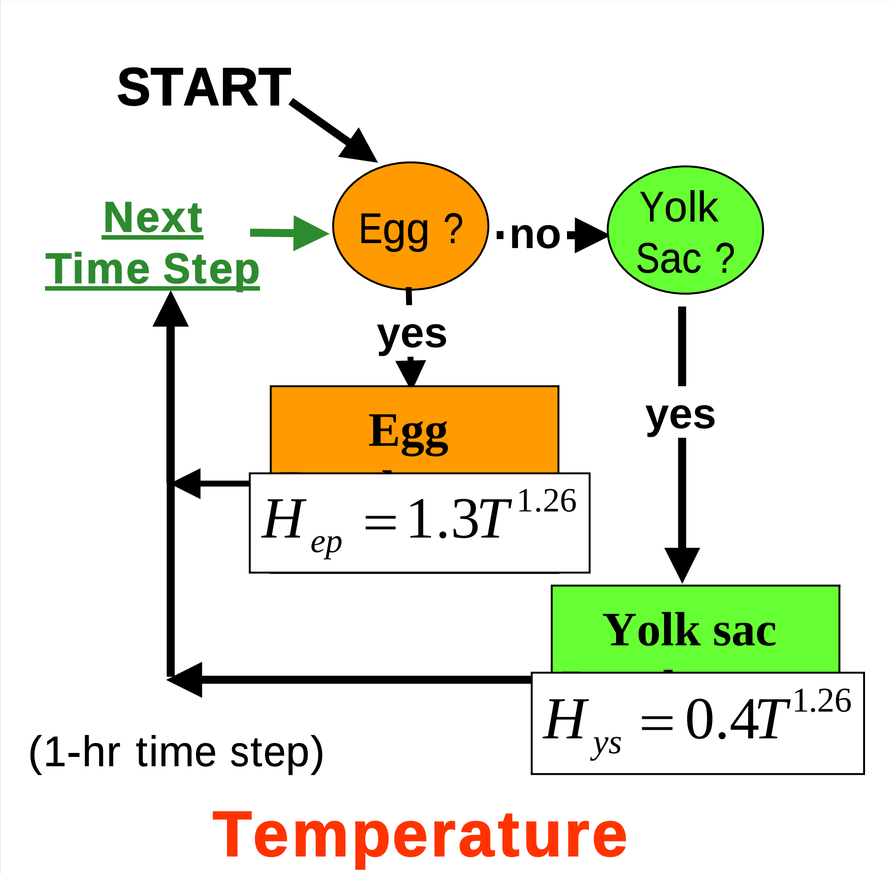
1-D IBM to 3-D coupled models

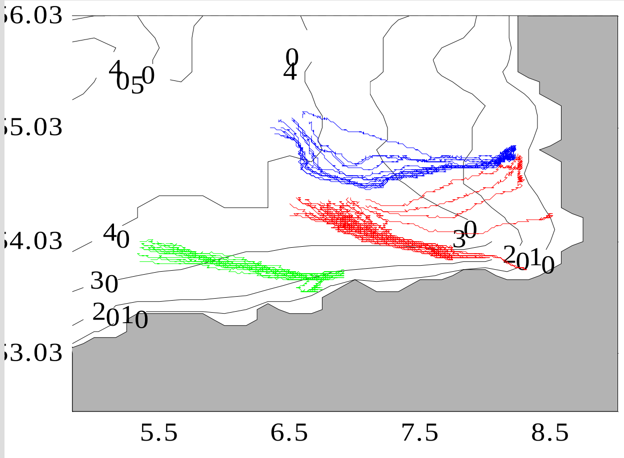
demersal gadid vs. pelagic clupeid

(*Gadus morhua*) **(*sprattus sprattus*)**

larval vital rates, temperature & prey availability

Part I: Eggs and Yolksac Larvae (simple IBM's)





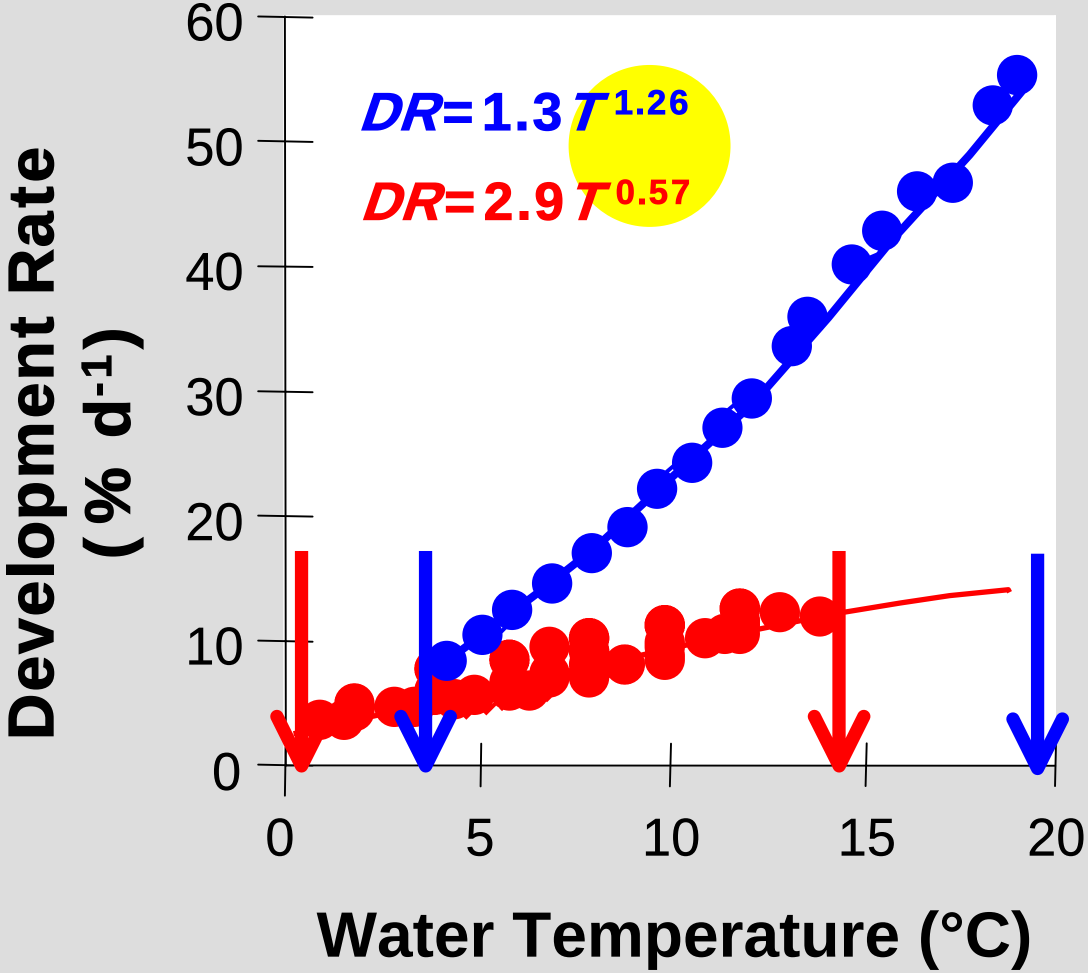
drift simulations

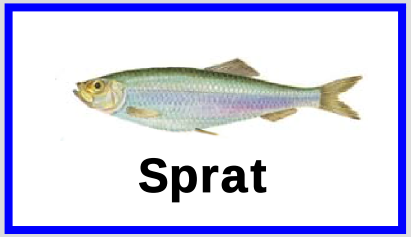
Climate impacts on:

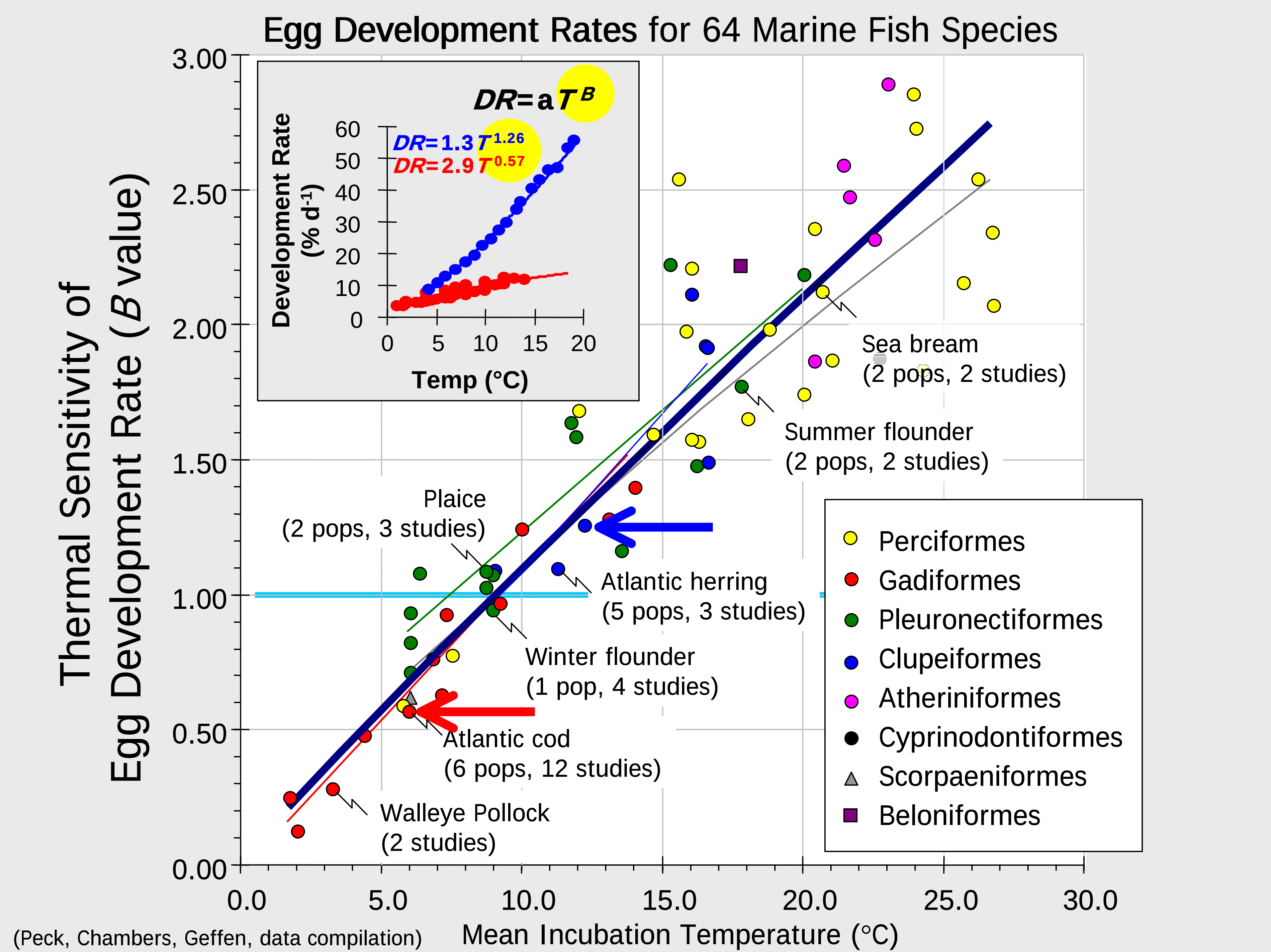
Transport
Habitat connectivity
Life cycle closure

Egg Development Rates vs. Temperature

$$DR = aT^{B}$$

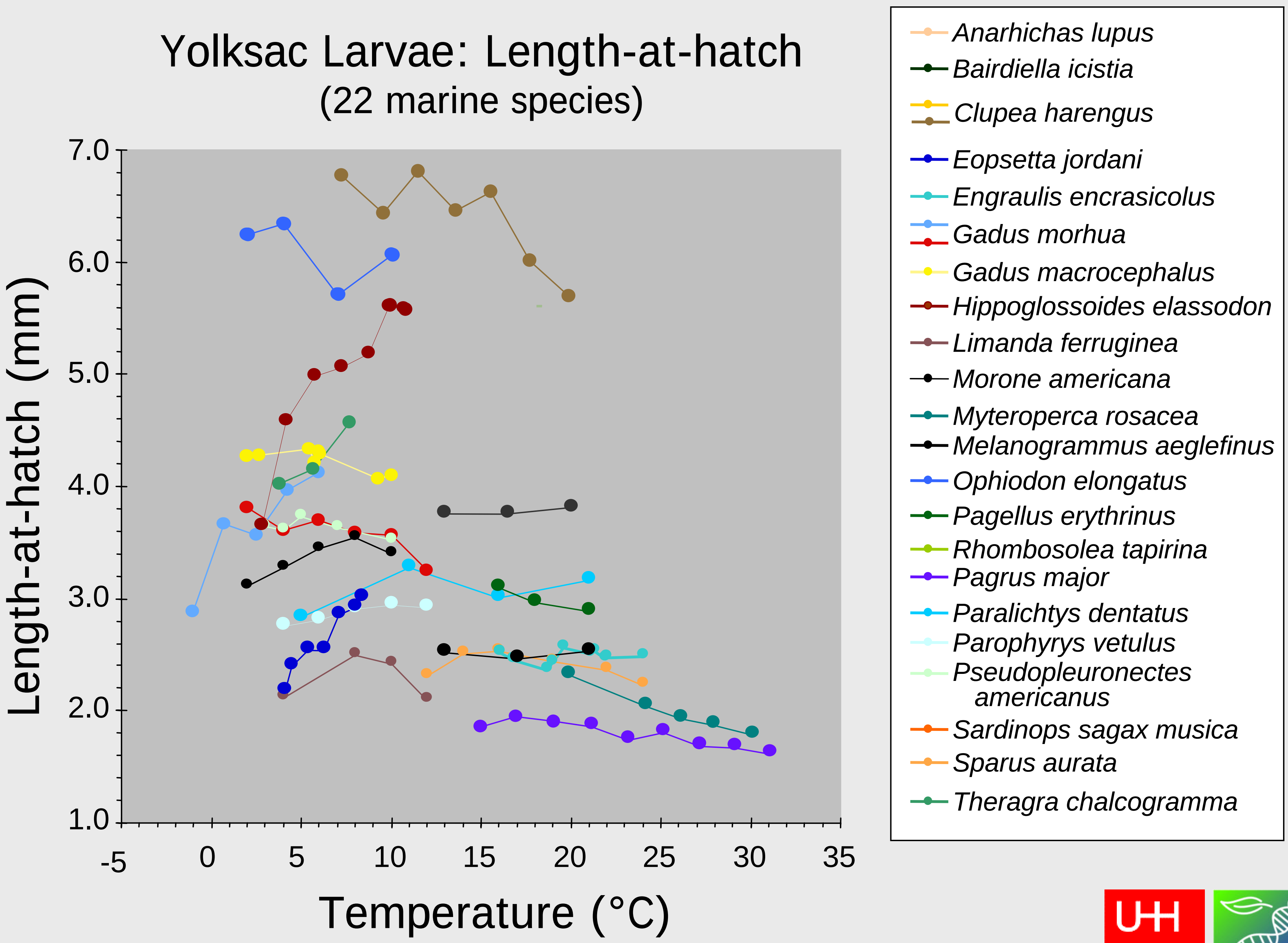






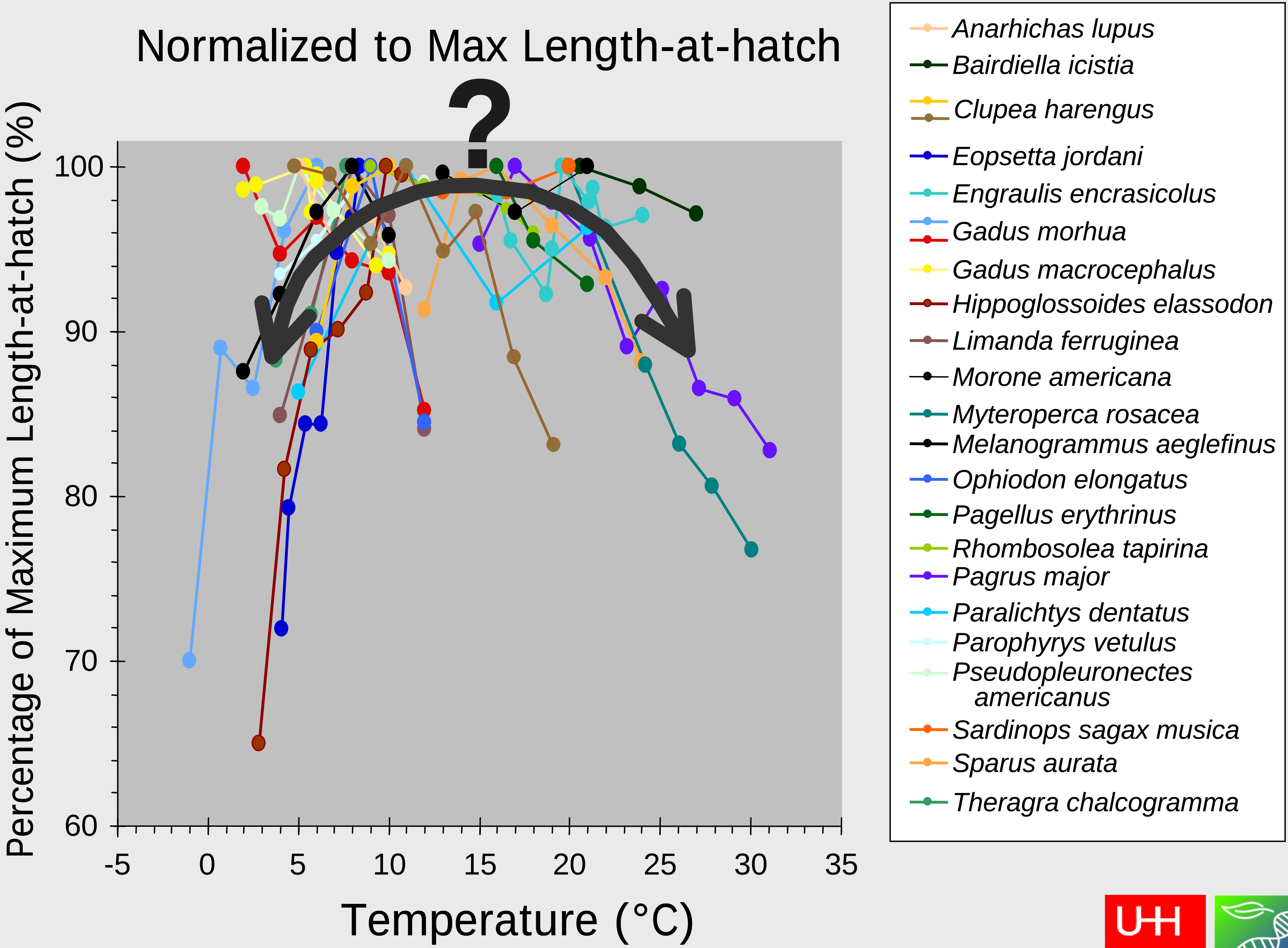
(Peck, Chambers, Geffen, data compilation)

Yolksac Larvae: Length-at-hatch
(22 marine species)



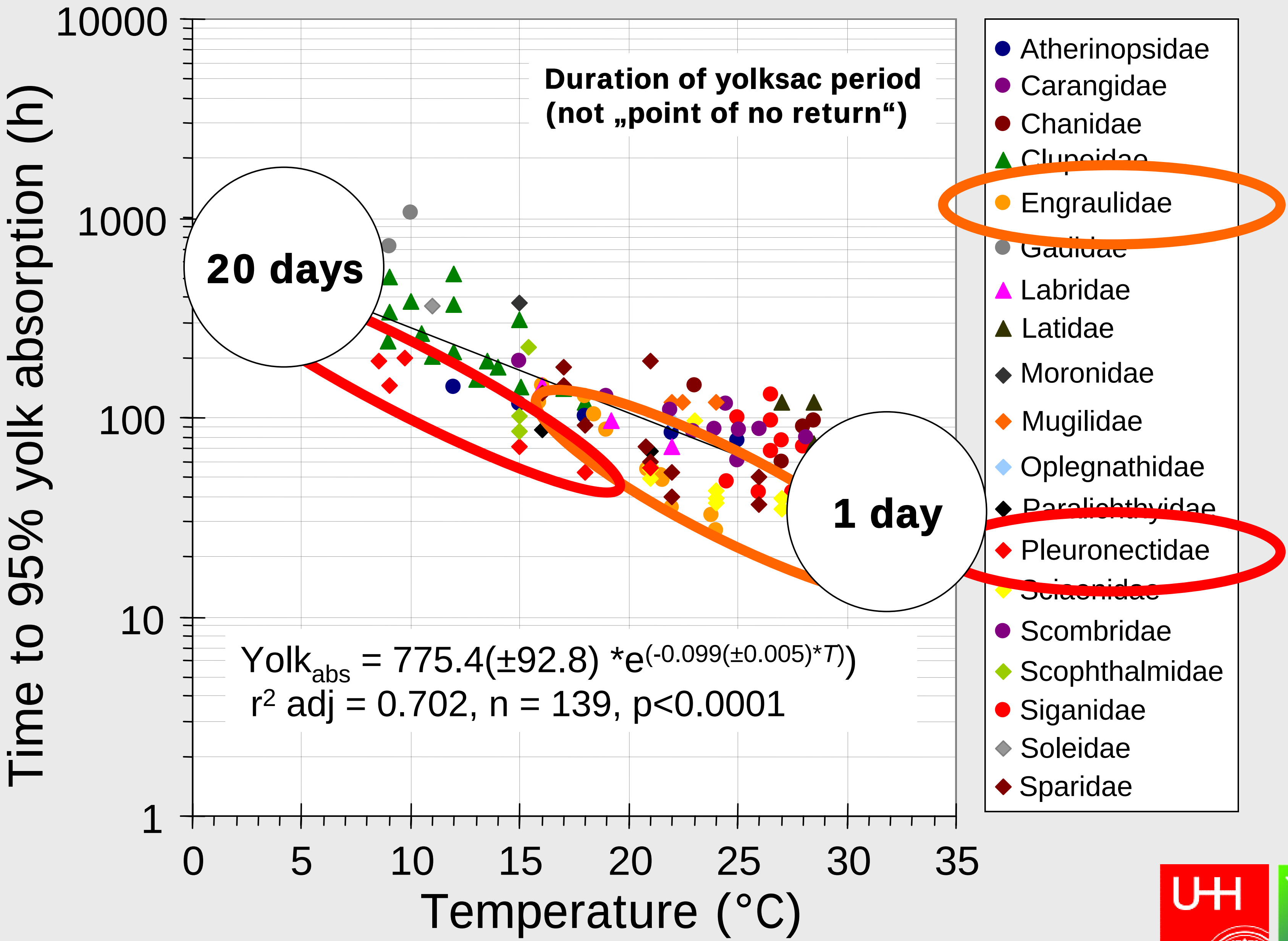
(M. Peck, & F. Bils unpublished compilation)

Normalized to Max Length-at-hatch



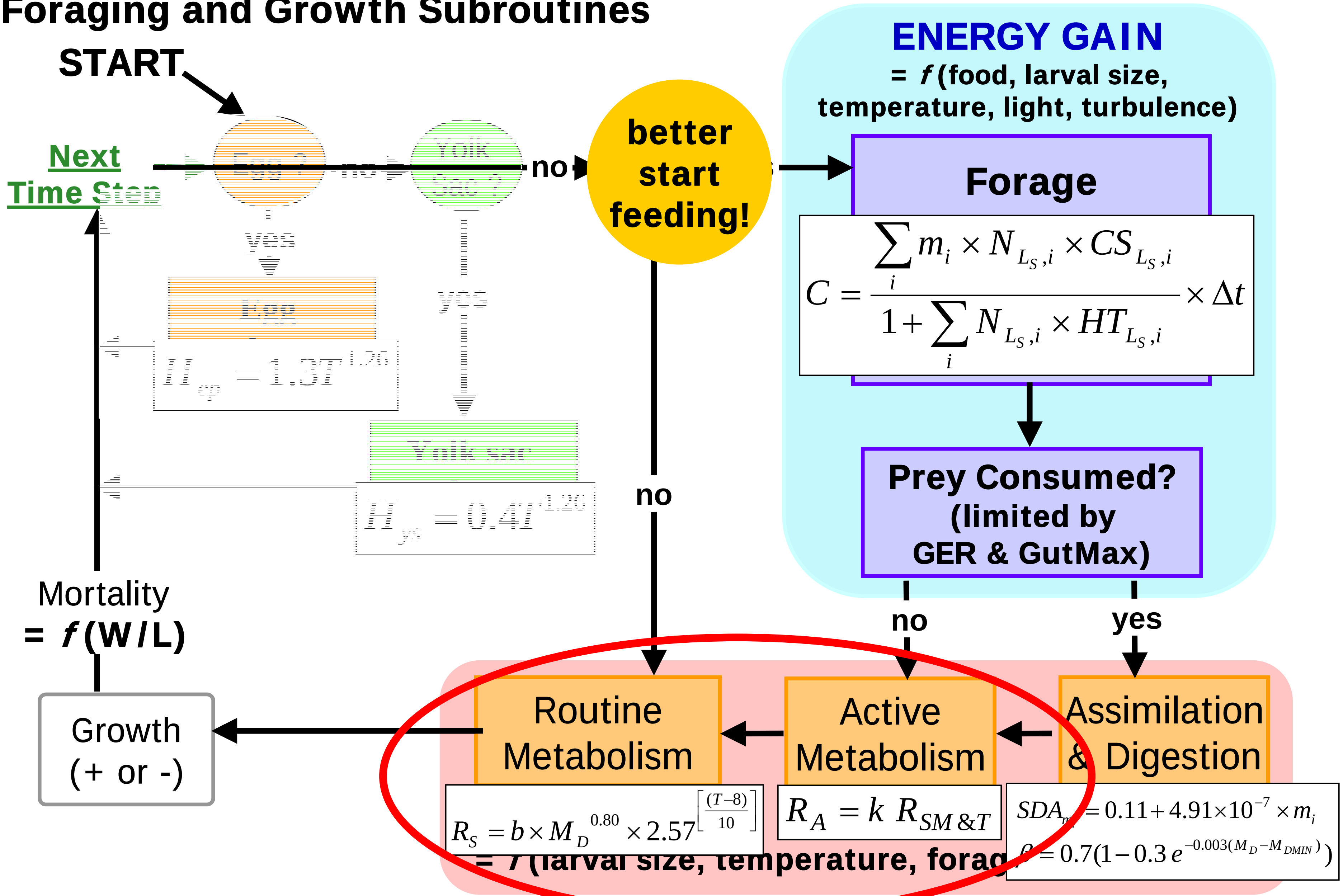
(M. Peck, & F. Bils unpublished compilation)

Best (but difficult) comparison is of individual slopes (more negative slope = most impacted by warming)

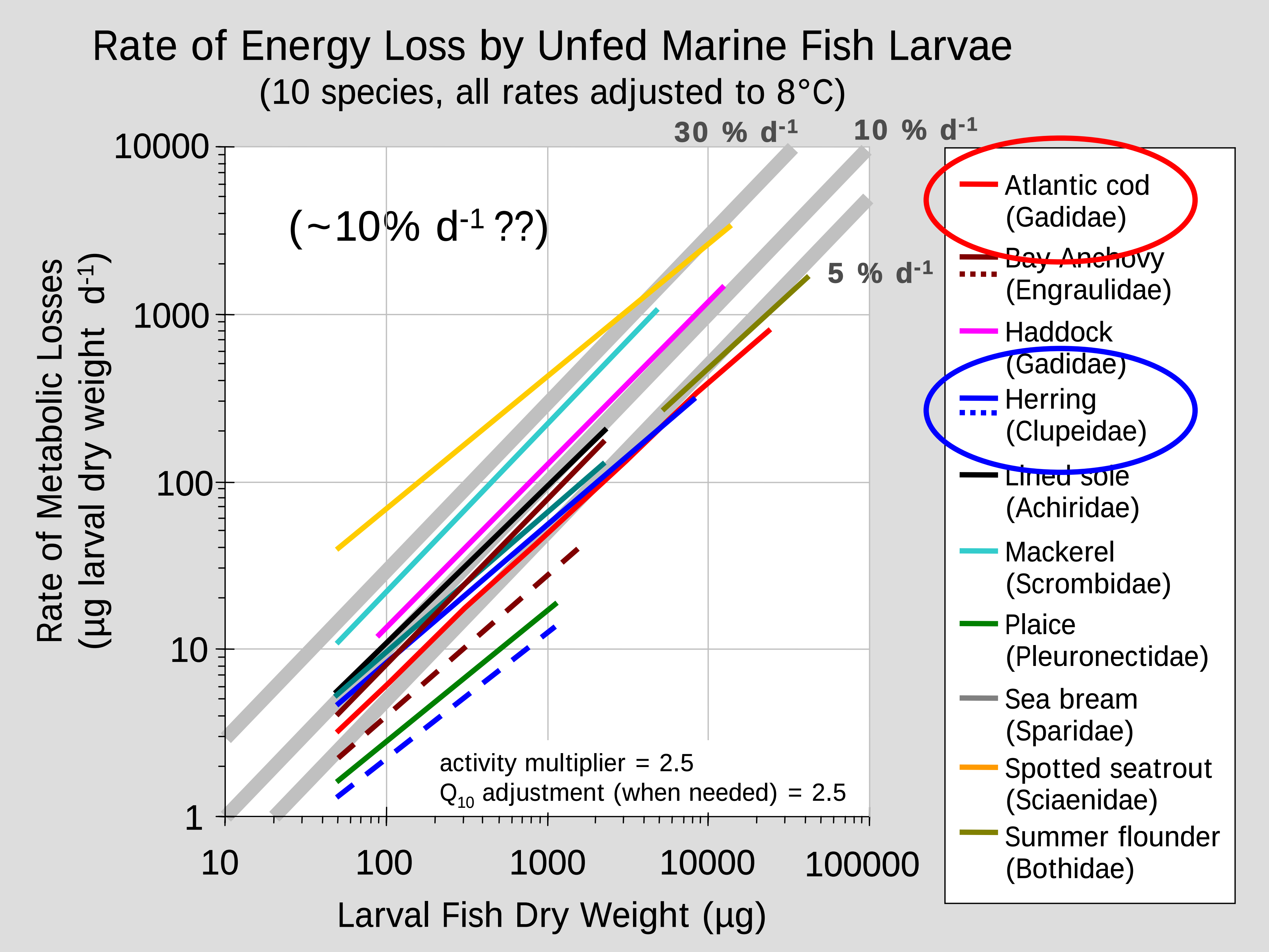


(M. Peck, & C. Lindemann unpublished compilation)

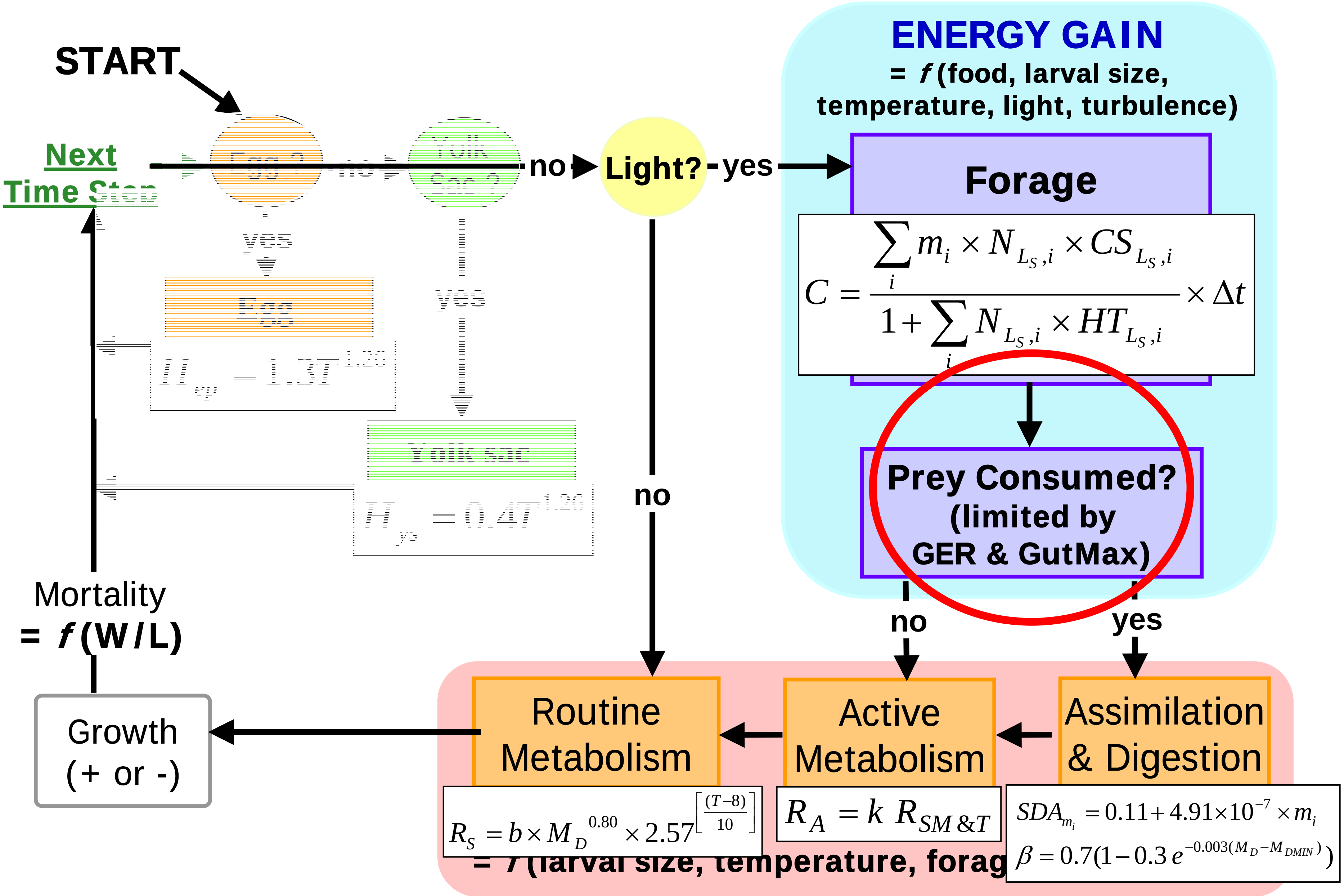
Part II: Exogenously-feeding larvae
Foraging and Growth Subroutines



1-hr time step


Rate of Energy Loss by Unfed Marine Fish Larvae
(10 species, all rates adjusted to 8°C)
30 % d-1
10 % d-1
5 % d-1
(~10% d-1 ??)
Rate of Metabolic Losses
(µg larval dry weight d-1)
10000
1000
100
10
1
10
100
1000
10000
100000
Larval Fish Dry Weight (µg)
activity multiplier = 2.5
Q10 adjustment (when needed) = 2.5
Atlantic cod
(Gadidae)
Bay Anchovy
(Engraulidae)
Haddock
(Gadidae)
Herring
(Clupeidae)
Lined sole
(Achiridae)
Mackerel
(Scrombidae)
Plaice
(Pleuronectidae)
Sea bream
(Sparidae)
Spotted seatrout
(Sciaenidae)
Summer flounder
(Bothidae)

Mechanistic IBM: Foraging and Growth Subroutines

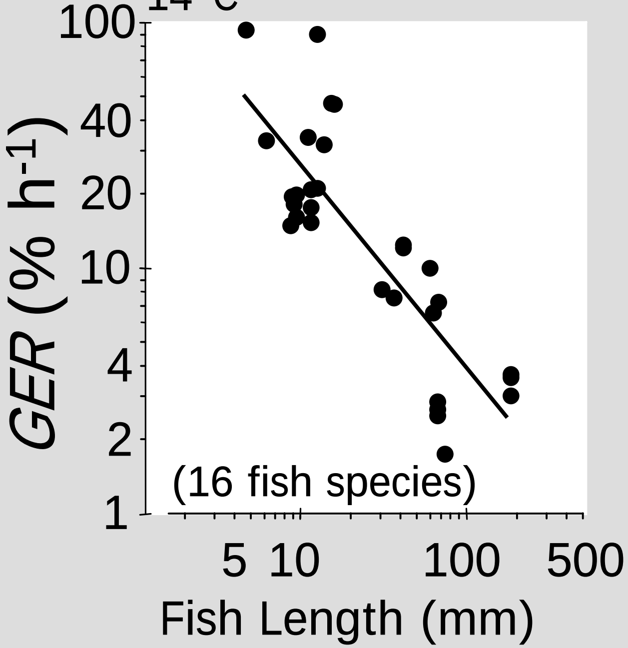


Rates of gut evacuation

- Single meal
- Constant feeding
  $CF = (2 \text{ to } 5) * SM$
- Temperature
  $Q_{10} \sim 2.0$

$GER = 1.79 * SL^{-0.83}$

14°C

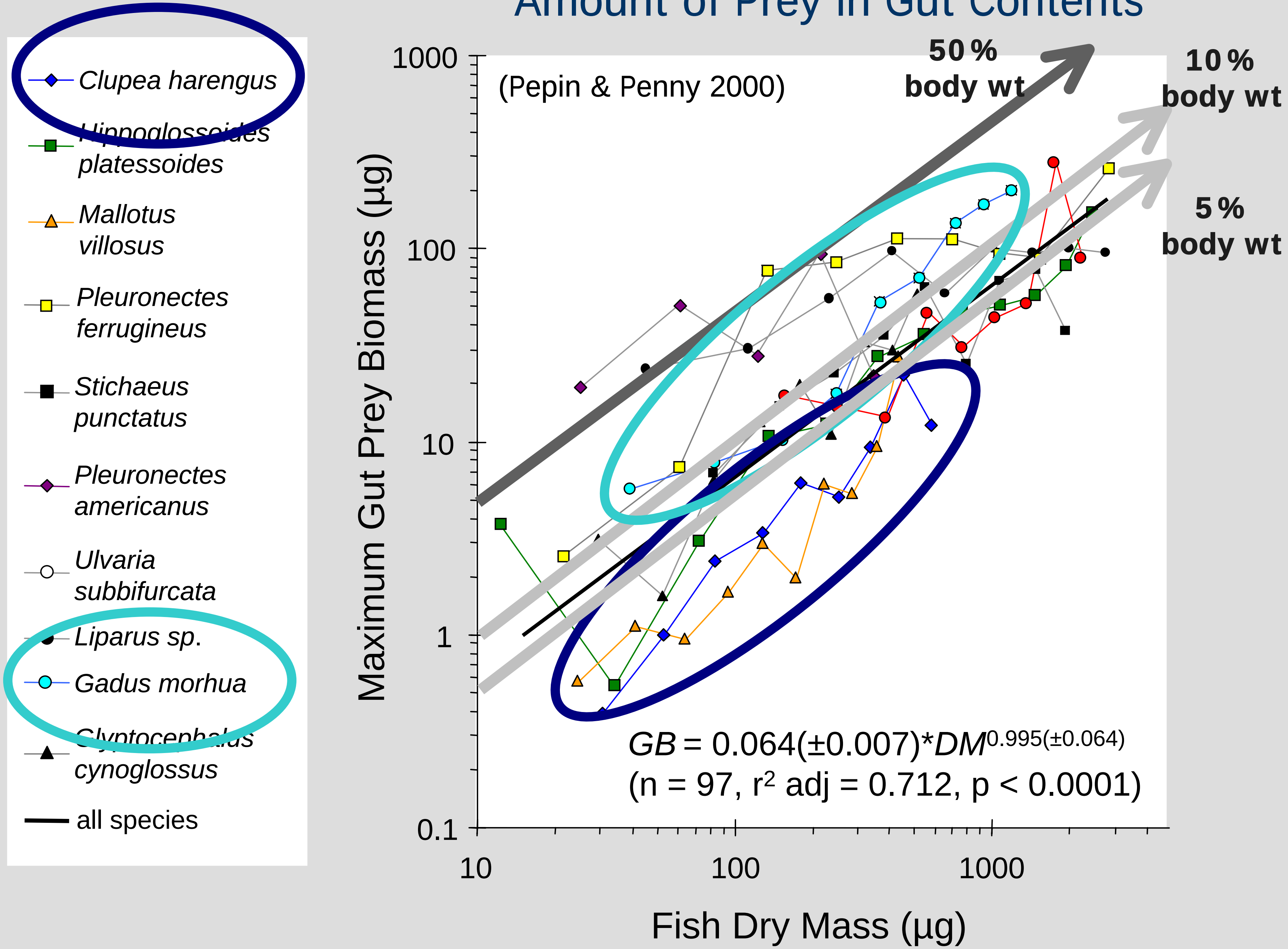


Species	Age (dph)	Length min	Length max	T (°C)	Prey Conc. (# l^{-1})	Evacuation Rate single (% h^{-1})	Evacuation Rate constant (% h^{-1})	Reference
Marine Species (13)								
Clupea harengus	np	10	12	7	np	0.111		Blaxter 1962
				11		0.200		
				15		0.222		
Clupea harengus	12	9	9	8	np	0.125		Blaxter 1965
				15		0.250		
Clupea harengus	8-22	10.5	12	6-9	$4\text{-}5*10^{3}$	0.667		Fossum 1983
Clupea harengus	26-40	12.5	18.1	9.5	0.011-0.198	0.400	0.706	Pedersen 1984
Clupea harengus	21-63	np	np	9.2	$3*10^{1}\text{-}10^{2}$	0.143		Werner & Blaxter 1979
					$3*10^{3}$	0.200-0.333		
					$3*10^{4}$	0.250-0.170		
Clupea harengus		35	74	np	in situ	0.178		Arrhenius & Hansson 1994
Cynoscion regalis	np	60	70	24	np	0.121-0.219		Lankford & Targett 1997
Gadus morhua	7		(4-5)	5	np	0.500-0.667		Tilseth & Ellertsen 1984
Logadon rhomboids					in situ	0.380		Peters and Kjelson 1975
Sardinops sagax		10.1	13.9	20	in situ	0.500-0.250		Herrera & Balbontin 1983
Sebastes malanops	np	35	93	7	ad libitum	0.019		Boehlert & Yoklavich 1983
				12	ad libitum	0.029		
				18	ad libitum	0.039		
Sprattus sprattus	np	13	16	8-15	in situ	0.460		Peck et al. (unpubl. data)
Syngnathus fuscus	np	150	200	15	np	0.038		Ryer & Boehlert 1983
				23	np	0.078		
				27	np	0.107		
Theragra chalcogramma	< 7		(5.92)	6.2	1200 - 1500	0.207-0.246		Canino & Bailey 1995
Thunnus alalunga	np	2.7	10	26	in situ	0.333-0.250		Young & Davis 1990
Thunnus maccoyii	np	2.7	10	26	in situ	0.333-0.250		Young & Davis 1990
Trachurus declivis.	np	2.4	14.3	15-18	in situ	0.167 - 0.25		Young & Davis 1992
Ulvaria subbifurvata	np	4	13	14	in situ	0.165-0.290		Bochdansky et al. In Press
Freshwater Species (9)								
Cyprinus carpio	np	8	12	18-29		0.050	0.125-1.000	Chiba 1961
Coregonus albula	14		8.7	18	np	0.280		Karjalainen et al. 1991
Dorosoma cepedianum	np	25	89	21	np	0.130-0.250	0.550-1.250	Shepherd & Mills 1996
Micropterus salmoides	np	20	60*	18	np	0.192	0.357	Laurence 1971
				23		0.263	0.500	
Perca Flavescens	np		(17-19.5)	21	np	np	1.667	Noble 1973
			30-40	22	np	0.154	0.667	
			(60)	15	np	0.083	0.167	
Perca Flavescens	np	20	69	14-21	np	np	0.417-3.333	Mills et al. 1984
Perca fluviatilis	np		(13.1)	np	field	0.400		Worischka & Mehner 1998
Salmo salar	np	43	99	9-13	np	0.017	0.068	Talbot et al. 1984
Stizostedion lucioperca	np		10.6	np	field	0.430		Worischka & Mehner 1998
Stizostedion vitreum	np	10.4	16.2	15	np	0.109		Johnston & Mathias 1996
				20	np	0.245		
				25	np	0.106		
Stizostedion vitreum	21		(29.4)	22	np	0.167	0.500	Corazza & Nickum 1983

*estimate based upon range in dry weights (196 to 721 mg)

(Peck & Daewel 2007)

Amount of Prey in Gut Contents



1-D to 3-D Modelling of potential survival & growth (gadoid vs clupeid larvae)

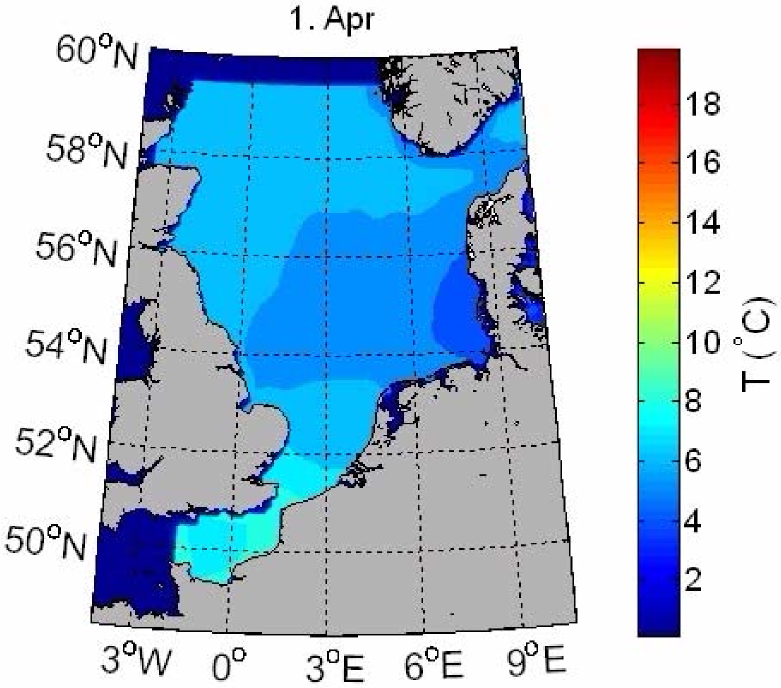
Temperature-dependent energy loss
(daily, active metabolism, etc.)
vs.
Temperature-dependent energy gain
(prey size, gut evacuation & gut biomass, etc.)

Atlantic Cod

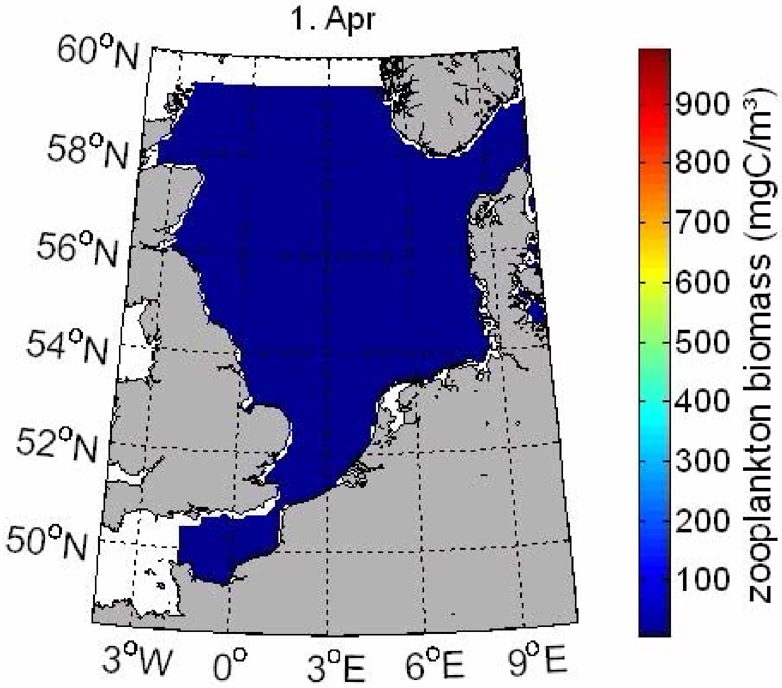
Sprat

3-D coupled model system (NPZD component)

Temperature



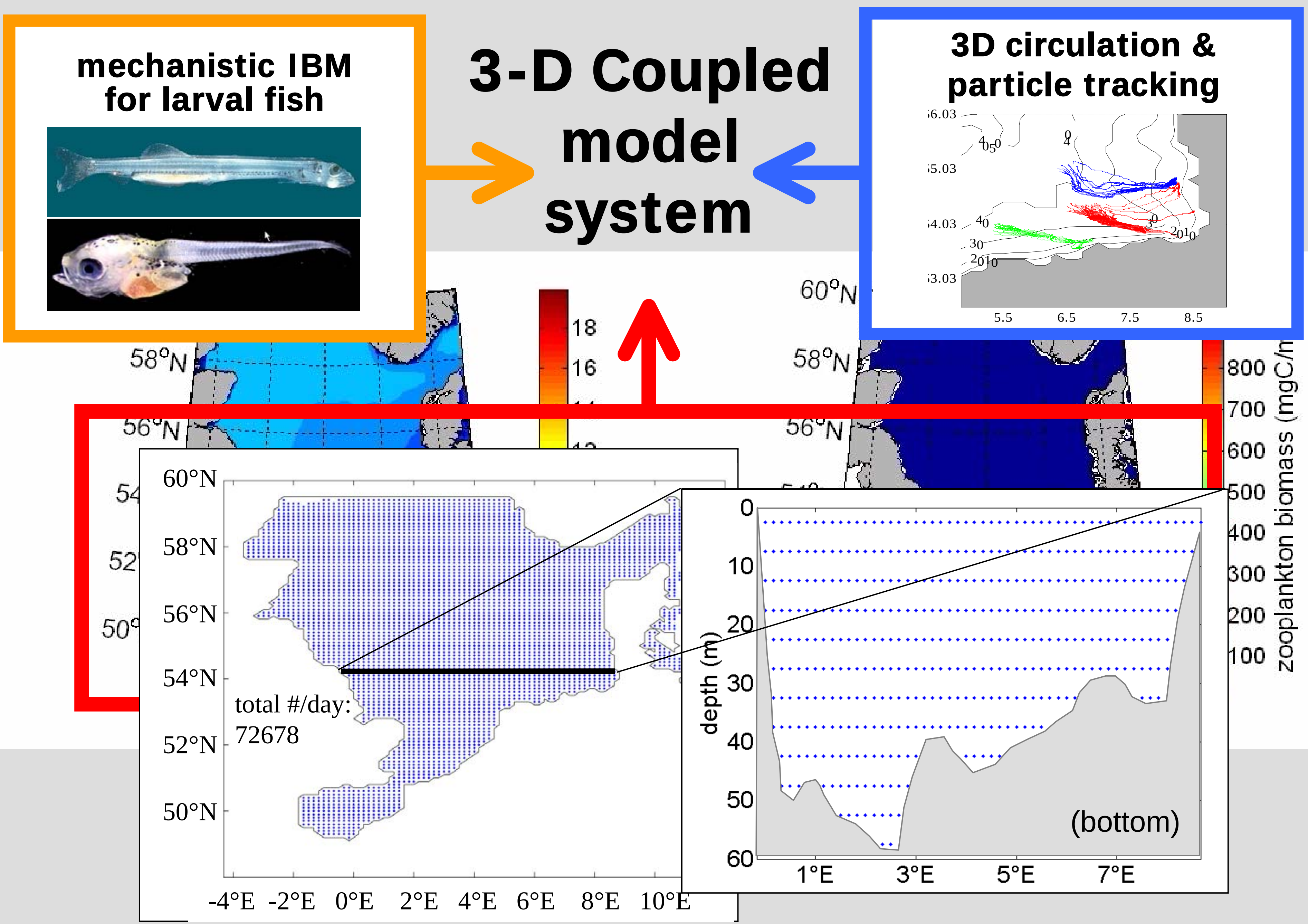
Seasonal Zooplankton Dynamics



Year = 1993
all values depth-averaged

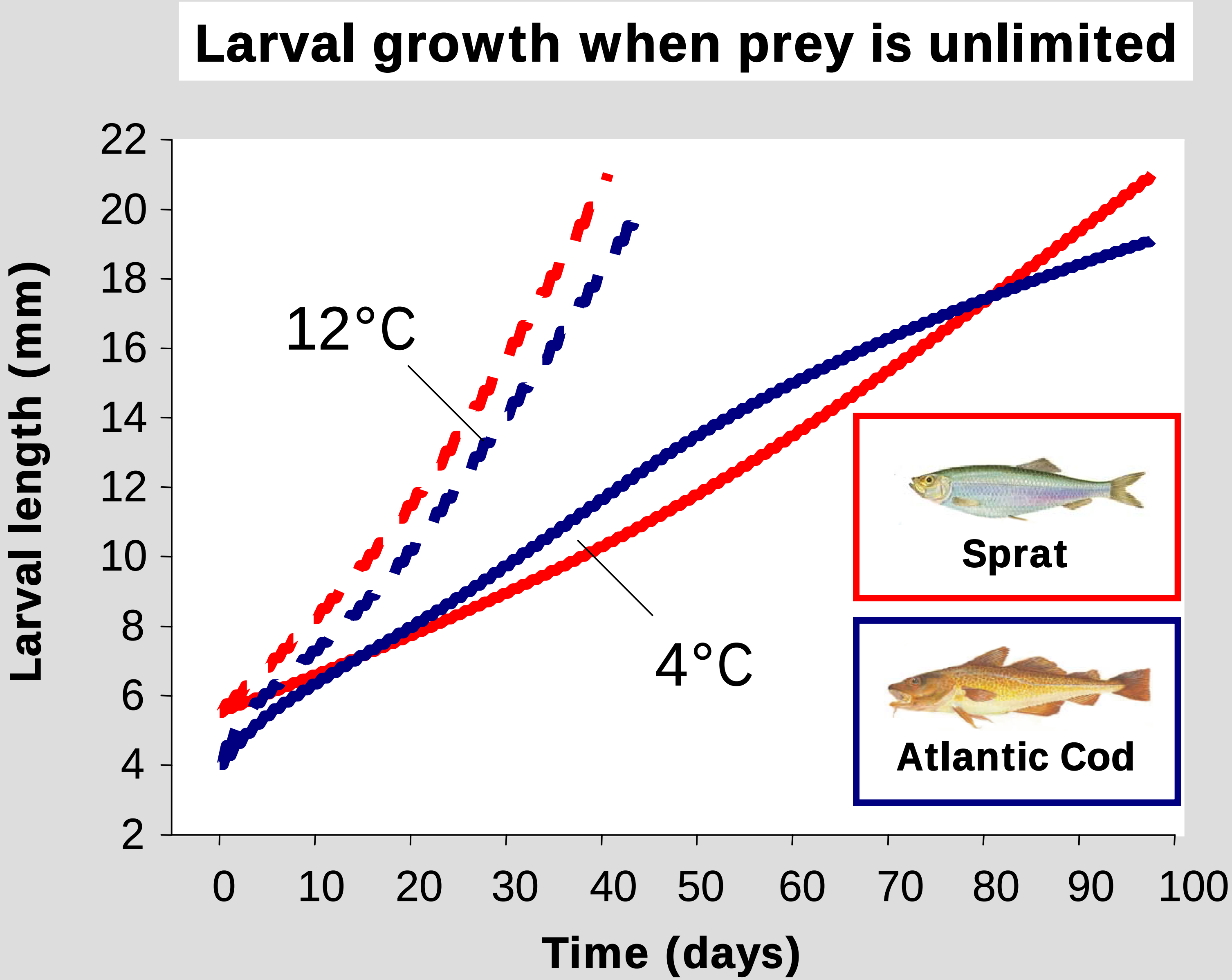
Ecosystem Model
2 Phytoplankton groups
2 Zooplankton groups
3 Nutrient cycles

(C. Schrum, Univ. Bergen)



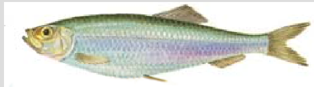
(Daewel et al. 2008 Fish Ocg.)

But, first some simple 1-D results....



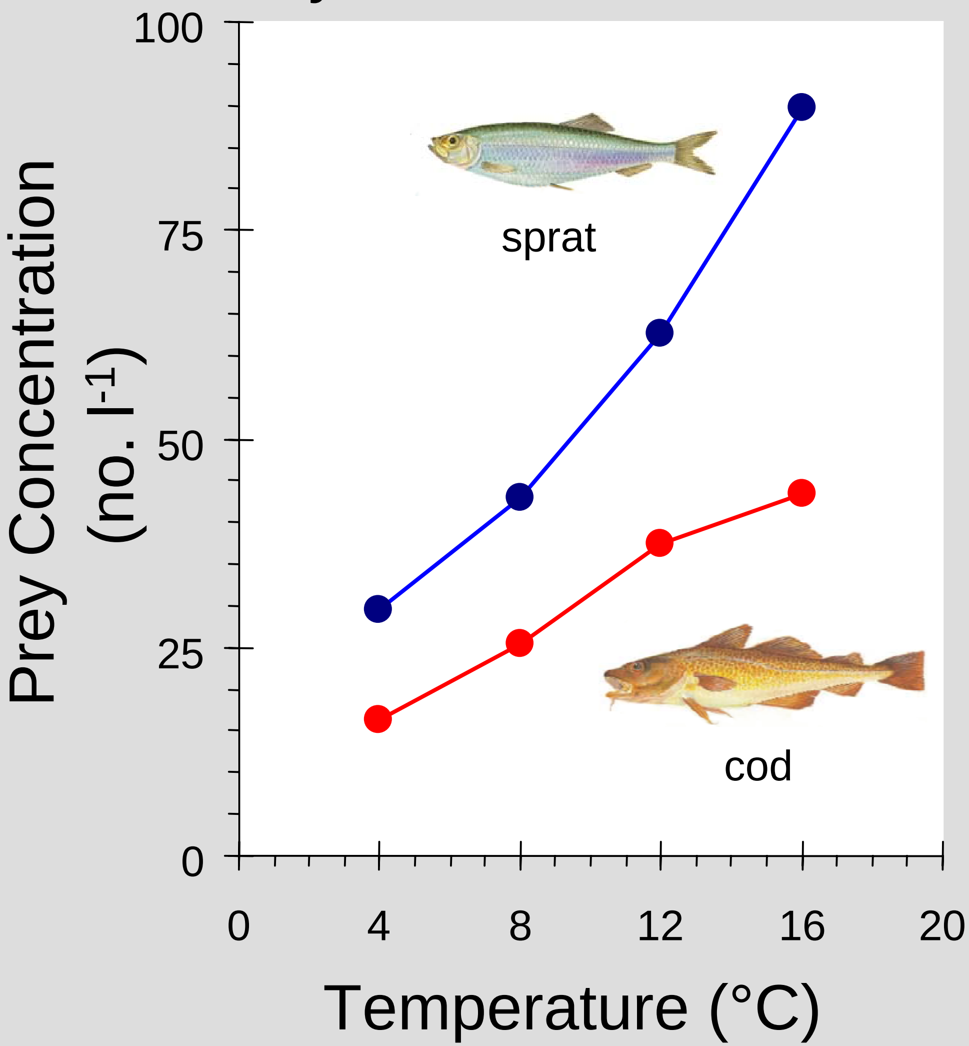
1-D model) temperature-specific prey requirements

First-feeding
150 - 700 µm prey



First-feeding
150 - 300 µm prey

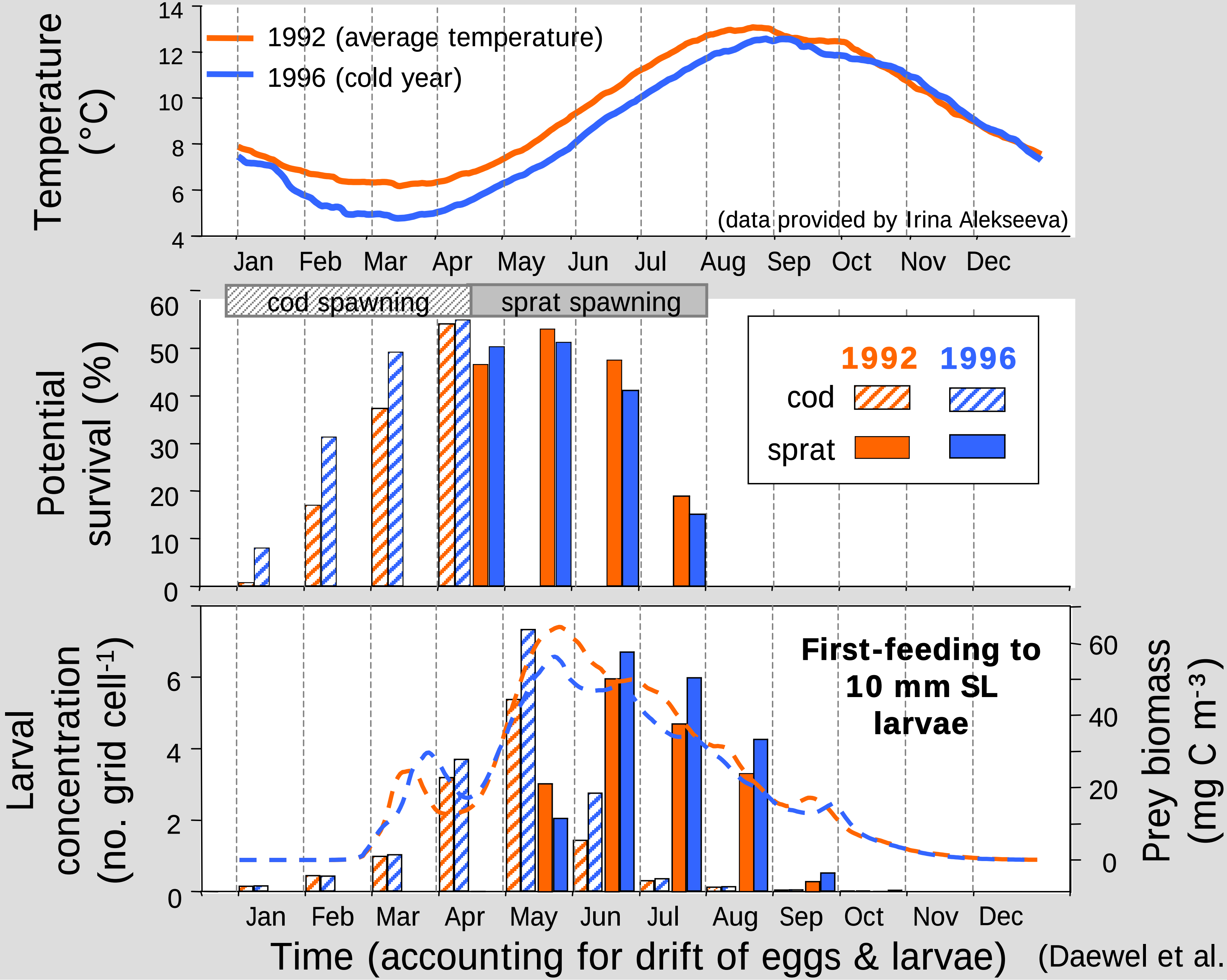
Prey Threshold for Survival



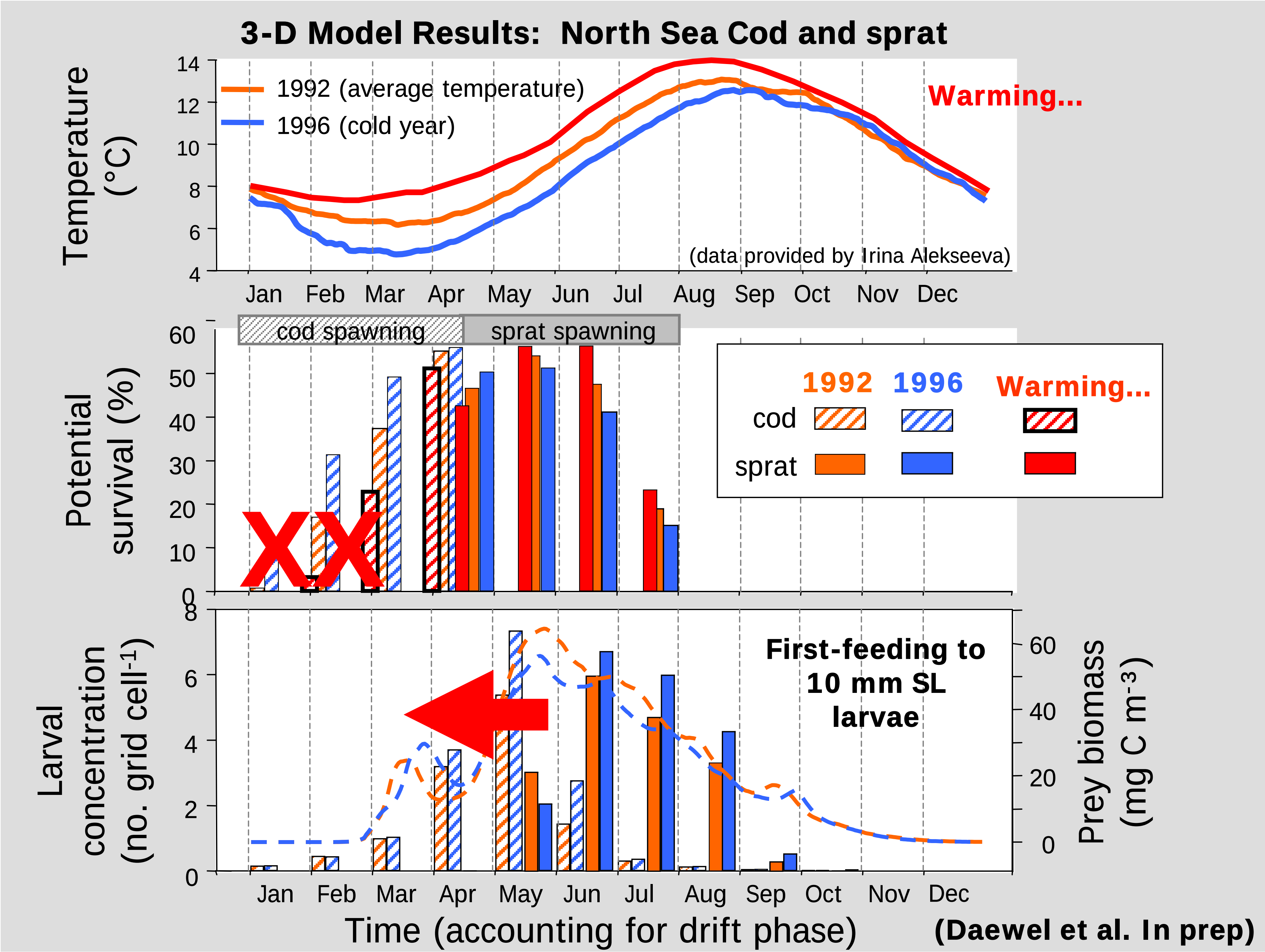
Fish don't eat carbon...

(converted to copepods in size classes available to first feeding larvae)

3-D Coupled Model Results: North Sea Cod & Sprat

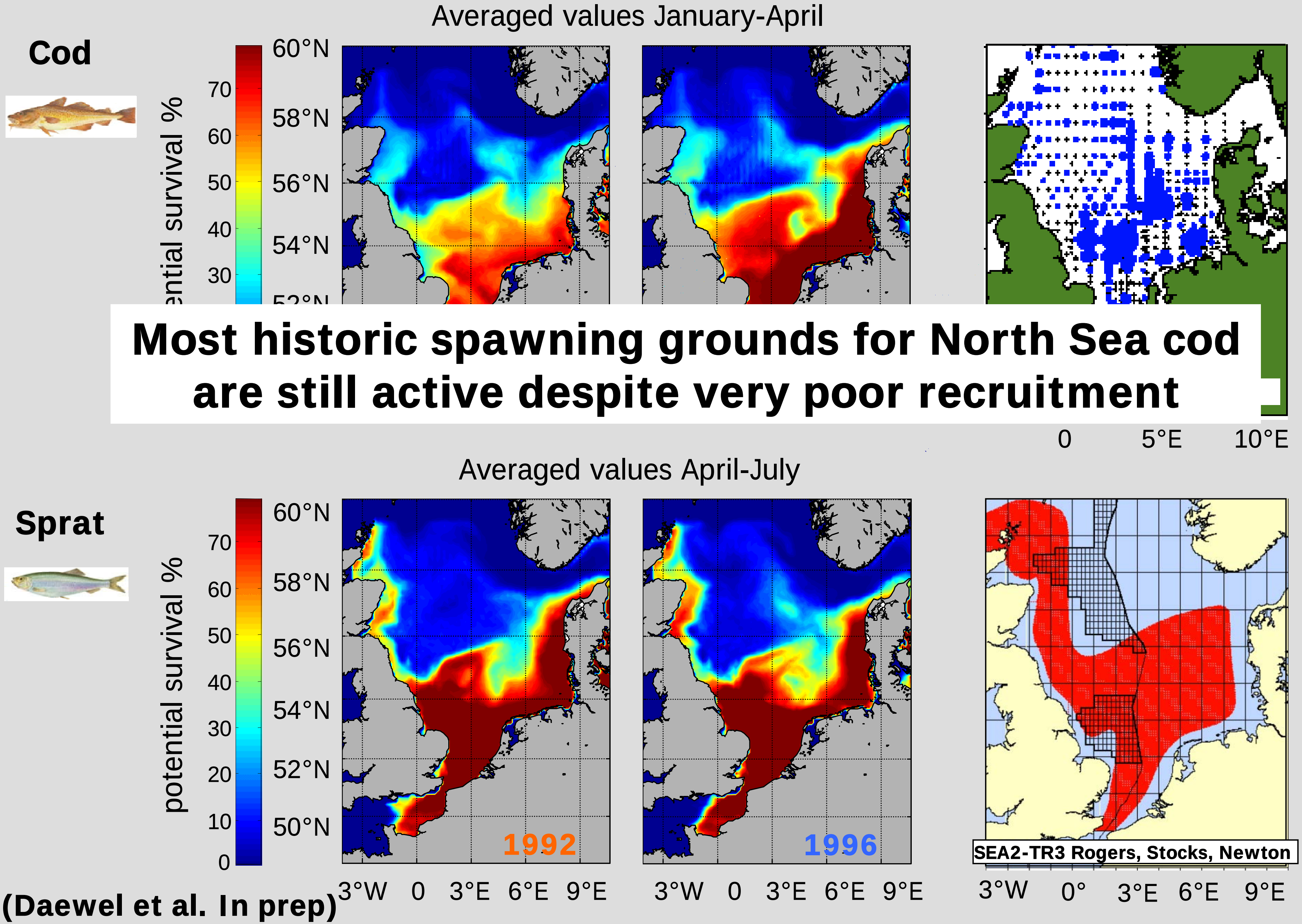


(Daewel et al. In prep)



3-D Model Results: North Sea Cod and sprat
Temperature (°C)
1992 (average temperature)
1996 (cold year)
Warming...
(data provided by Irina Alekseeva)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
cod spawning
sprat spawning
Potential survival (%)
1992 1996 Warming...
cod
sprat
Larval concentration (no. grid cell-1)
First-feeding to 10 mm SL larvae
Prey biomass (mg C m-3)
Time (accounting for drift phase)
(Daewel et al. In prep)

3d coupled-model: areas supporting potential survival compared to observations



Most historic spawning grounds for North Sea cod are still active despite very poor recruitment

(Daewel et al. In prep)

Summary & Conclusions I

Considerable variation exists in physiological attributes of marine fish early life stages that are directly impacted by climate – examples:

Eggs

Change in Development Rate vs Temperature

Yolksac Larvae

Change in size-at-hatch vs temperature
Change in the time to end of yolk reserves vs temperature

Feeding Larvae (inter-specific differences)

rate of energy loss when unfed
maximum biomass of prey in gut & prey size vs body size

Examine interlinkages among physiological traits & rates that change with body size & / or temperature
(C = G + R + E + F)

Summary & Conclusions II

Biophysical IBMs can test how species-specific differences in physiological traits may influence severity of climate impacts on early life stage vital rates (e.g., cod vs sprat in North Sea)

Growth response & temperature

Similar in larval cod & sprat when provided unlimited prey

Prey thresholds for survival & growth

Differ between cod & sprat (cod has larger prey field + higher max. gut content, and species have similar energy losses)

Match-mismatch and warming

Fidelity to spawning site & time may lead to severe mismatch between cod larvae & zooplankton production. Sprat appears much less vulnerable to warming.

Work is ongoing with coupled NPZD-IBM ...

(e.g., inter-annual (20+ yr) comparison for both species)

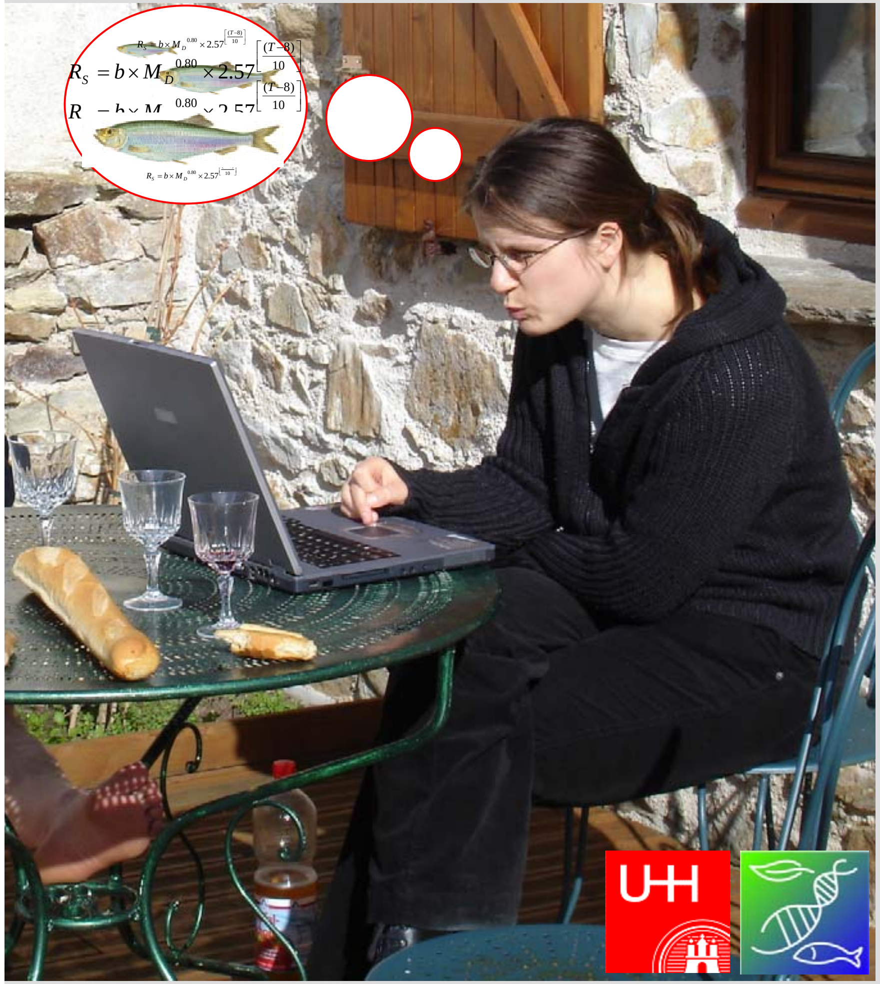
Acknowledgements

Data Sets

Franziska Bils
Christian Lindemann
Christof Schneider
Audrey Geffen
Christopher Chambers
Greg Lough:

Co-authors

Ute Daewel (hard at work)
Corinna Schrum



Thanks for your Attention!

Questions?, Comments... ... Lunch?